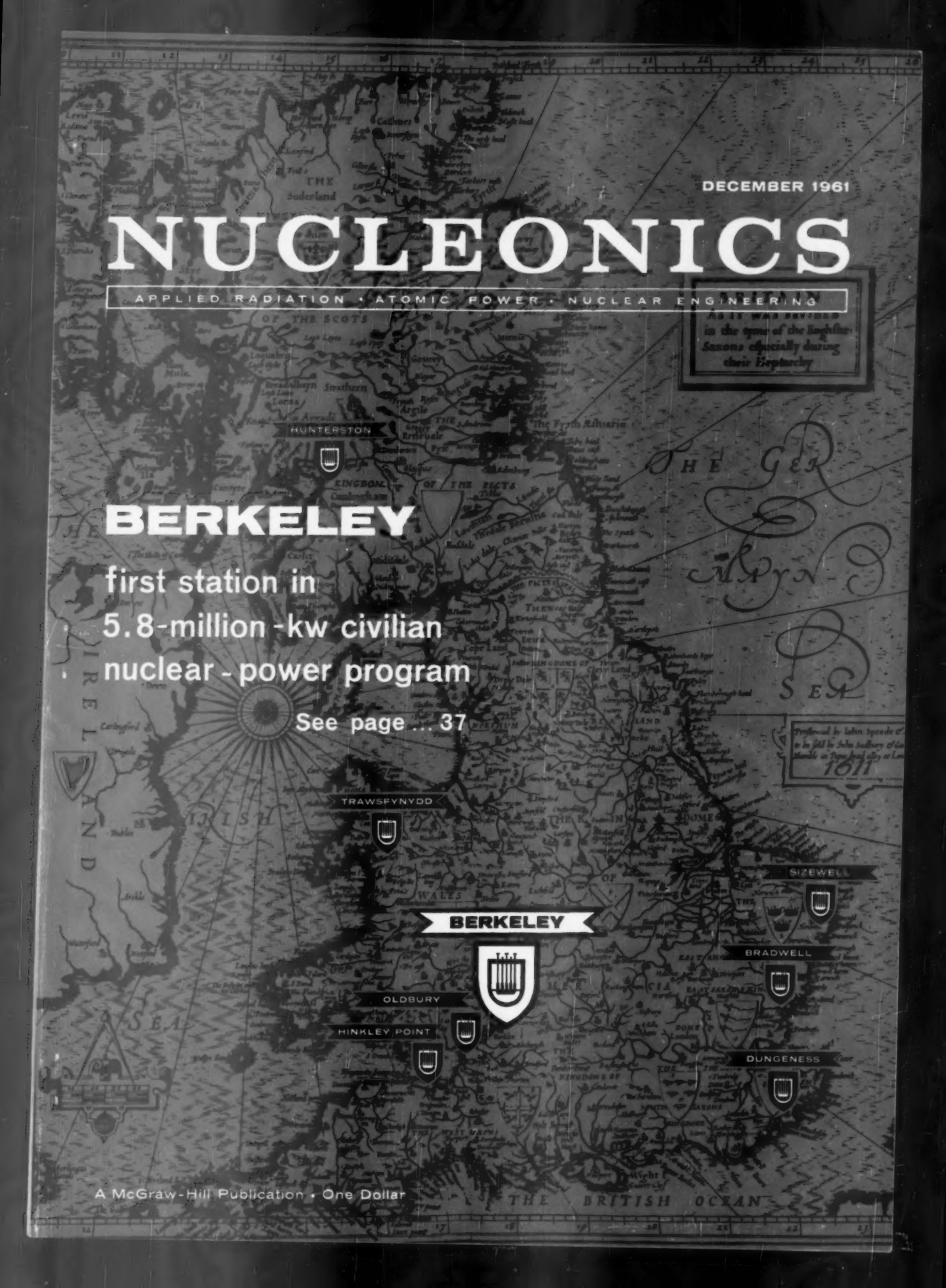
DECEMBER 1961

NUCLEONICS

APPLIED RADIATION • ATOMIC POWER • NUCLEAR ENGINEERING



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Above, technicians mark segment of casting for one of many hundreds of X-ray pictures employing a 24,000,000 volt Betatron at the Bonney Floyd Foundry. *Below*, X-ray picture is carefully inspected for flaws.

Shown here is the largest single-piece stainless steel pump casting built today. The X-ray procedure is just one of the many inspections necessary to assure the high quality in Worthington nuclear pumps. Special designs were necessary to allow a single casting to be made for this size pump.

A more complete discussion of special equipment criteria and manufacturing techniques for nuclear requirements is available in a Worthington pamphlet, "Manufacturing For a Nuclear Power Plant." Ask for RP-1092.

To provide the special attention required to engineer and manufacture nuclear products, Worthington has an Advanced Products Division which specializes in pumps and other equipment for nuclear plants. For further information, write Worthington Corporation, Nuclear Department 106-7, Harrison, New Jersey.

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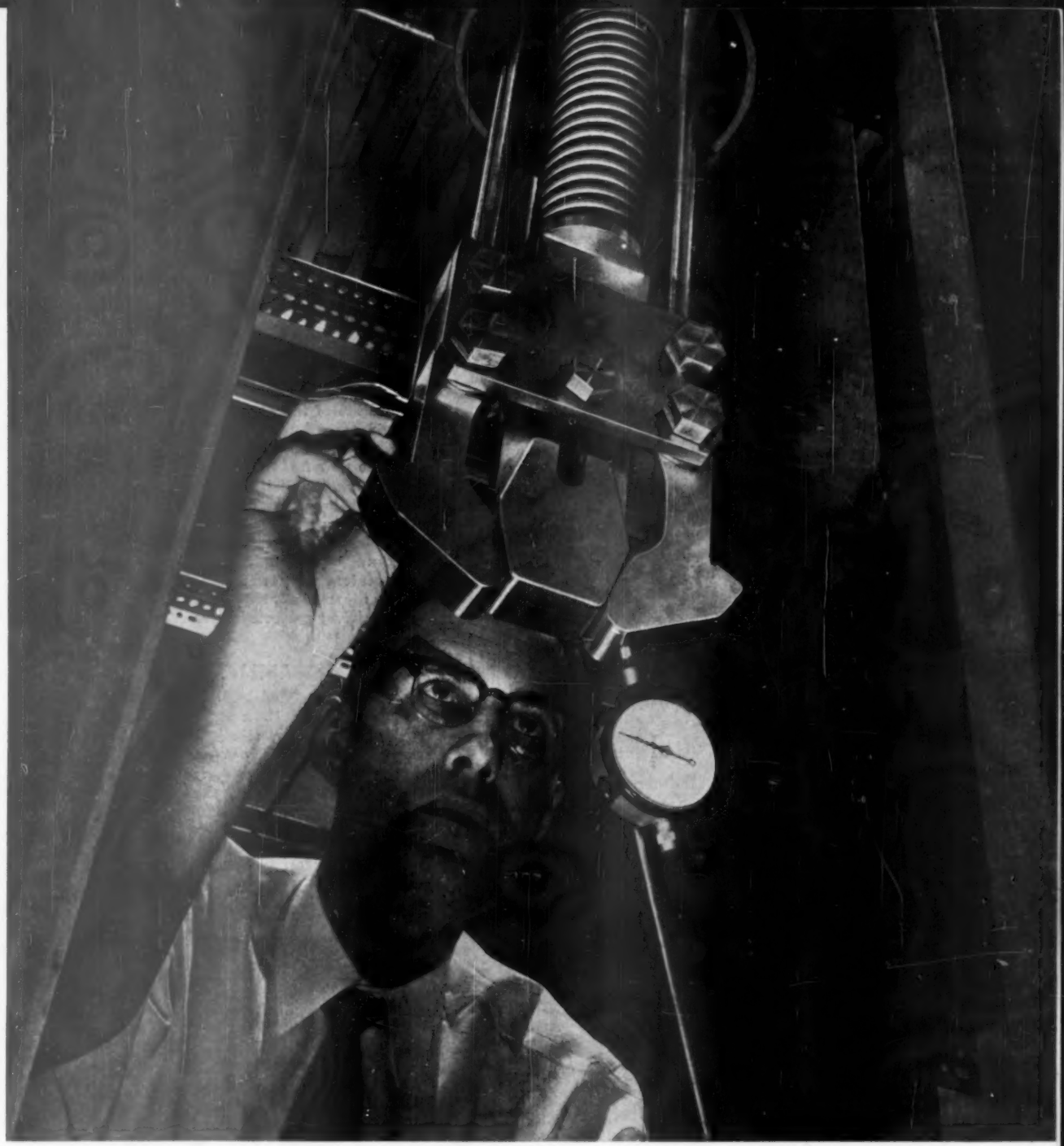

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Most reactors call for a spring mechanism to keep fuel elements in place, yet allow for thermal expansion.

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The bottom hold-down unit, another practical engineering feature developed in the nuclear laboratories of B&W, can be adapted to many core designs and configurations. For information write to The Babcock & Wilcox Company, 161 East 42nd Street, New York 17, New York. E-701-1002

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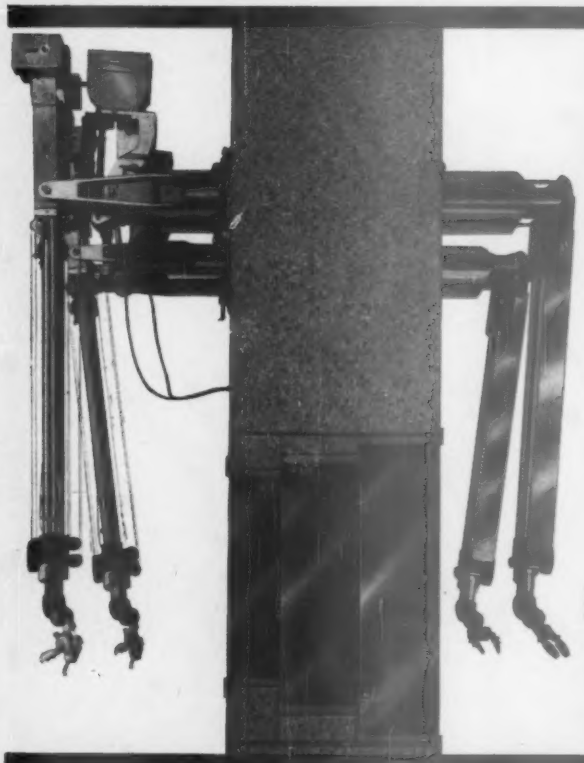

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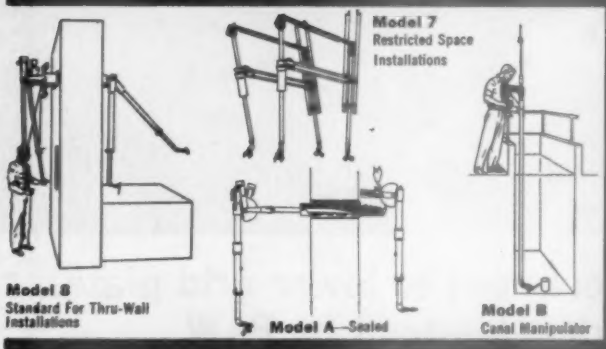

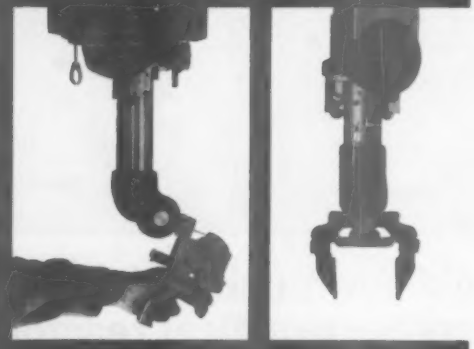

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APPLIED RADIATION • ATOMIC POWER • NUCLEAR ENGINEERING

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...about NUCLEONICS

Saw You at Chicago

Five of us editors were happy to meet and talk to many of you readers during Atomic-Industrial-Forum-and-American-Nuclear-Society week at Chicago. Still—a lot of you (and many of us) were tending store back home; you can't just shut down nuclear operations on a world-wide scale and take off for the lake shore. What's more important: the 72,000 readers of NUCLEONICS (we figure 3.6 readers per copy) would probably strain even Chicago at the seams if we all showed up there at once. So we want to tell the few thousand who weren't there about the NUCLEONICS booth.

Central attraction was our NUCLEONICS WEEK teletype receiver ringing its bells and spewing out news of the nuclear world. We wanted you all to see that our McGraw-Hill World News organization (look at the masthead to the left) is at work all the time to gather the material that makes NUCLEONICS News of the Month once a month and NUCLEONICS WEEK every week. Delegates to the show enjoyed reading of the Aerojet-General Nucleonics reorganization on teletype just before the "announcement" party.

Reprints and Microcards

If you watch the fine print, you may have noticed our offer of our NUCLEONICS Special Report on Radiation Chemistry (October, 1961) on a Microcard (the word is a registered trademark of The Microcard Corp., West Salem, Wis.). We used the offer to see how many readers are interested in this kind of reproduction and have been gratified to find that several are. Thus we intend to make available some of our special features—Data Sheets, Reactors-on-the-Line foldouts, Reference Data Issues—on future Microcards. Let us hear what you would like to see.

Of course if you really go for NUCLEONICS in this form, you may want to write to the J. S. Canner Co. (618 Parker St., Boston, Roxbury 20, Mass.), which offers complete Microcard volumes for the years 1947–1956.

That's not the only way to get back copies. The Johnson Reprint Corp. (111 Fifth Ave., N. Y. 3, N. Y.) has a contract under which they reprint and bind NUCLEONICS. We also send them unused copies of back issues; so when other supplies fail, Johnson Reprint has either the back copies that readers ask for or reprints of them.

Write for Your Index

And speaking about back copies of NUCLEONICS, where is the index that *always* appears at the end of the December NUCLEONICS? It's not there this year; we saved the pages it would occupy so that we could give you more pages in the regular editorial section. But we do want you to have an index if you have use for it. Just write to us and ask for it.

The 1961 index is in preparation and will be printed in a form appropriate for storing or binding with your issues. As in the past, it will have both subject and author sections, and it will list all of the regular editorial matter of the magazine: articles, news stories, staff-written items.

We will send it free to anyone who asks. So send for your copy, and above all, don't let your library bind the volume without first getting the index to bind with their issues.

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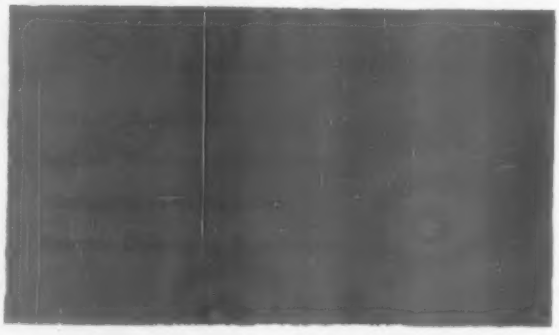


MARTIN NUCLEAR ROCKET PROGRAM

- REACTOR DESIGN
- PROPULSION REACTOR START-UP
- NUCLEAR ROCKET SAFETY ANALYSIS
- RADIATION EFFECTS ON ROCKET SYSTEM
- FUEL ELEMENT DEVELOPMENT
- VEHICLE DESIGN
- CRYOGENICS

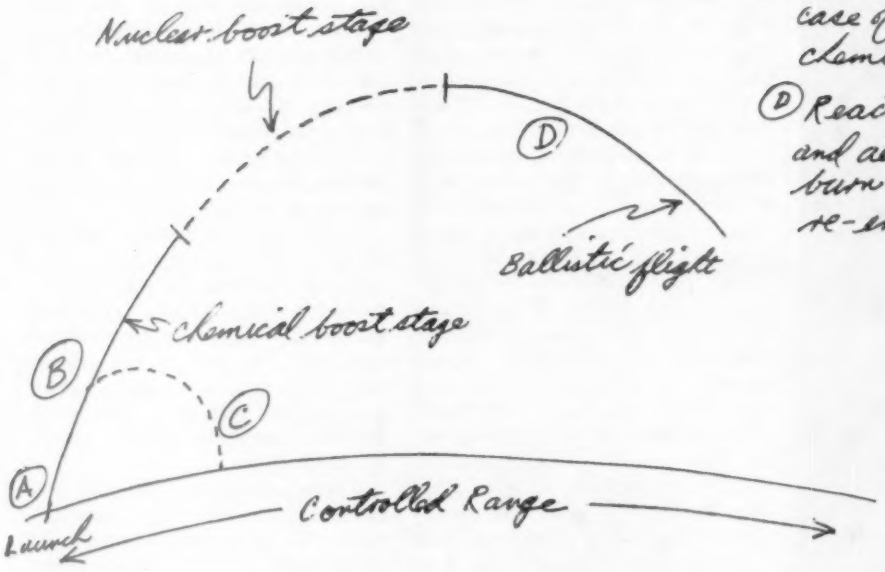
Safety Requirements

(A) Safe disposition of reactor in case of launch pad abort

(B) Rapid reactor start-up without risk of a nuclear excursion

(C) Safe disposition in case of abort during chemical boost

(D) Reactor fragmentation and aerodynamic burn-up during re-entry



SAFETY ASPECTS OF NUCLEAR ROCKET FLIGHT TESTING

Safety is one of the many areas receiving continuous attention in the U. S. nuclear rocket program. Tests must be conducted to obtain data, to develop safety systems, and to demonstrate safety.

During the past several years, Martin has gained valuable experience in the safety field through its investigations and tests concerning the use of radioisotope-fueled generators for auxiliary power in space. Analytical investigations of nuclear rocket safety conducted by the company under the RIFT (Reactor in Flight Test) program for the National Aeronautics and Space Administration are being continued. The U. S. Atomic Energy Commission's SNAP program, under which The Martin Company developed the radioisotope-fueled generator that powers two radio transmitters in a Transit satellite, involved exhaustive safety studies and tests. This was the first use of atomic energy in a space vehicle. Experience in computer analysis of booster behavior, flight test of large boosters (VIKING, VANGUARD, TITAN and PERSHING) at Cape Canaveral, re-entry, system integration, missile test range control and rocket destruct systems, as well as extensive experience in nuclear technology, has been invaluable in the development of technical capabilities and facilities required for these investigations.

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NUCLEAR REACTIONS

Isotope Dilution for Wastes

DEAR SIR:

About ten years ago I came up with some ideas on waste disposal and have discussed them on and off with the AEC during that time. Their response has recently been most gratifying. I would be interested to hear any comments from NUCLEONICS readers.

Almost all methods that have been suggested or explored to concentrate radioactive waste streams—particularly those of fuel-reprocessing plants—have the common weakness that they become less effective as the solution becomes more dilute. Since decontamination factors as high as 10^9 are desirable and frequently necessary, the effort to remove final traces consumes a major fraction of the cost of the process.

The only methods that do not lose their effectiveness at the trace-concentration level are foam separation and solvent extraction. Until a wide range of foaming-complexing systems is developed, however, the use of foam separation will be limited to a few selected radionuclides in a few specific waste streams. Solvent extraction also has chemical limitations, particularly with respect to alkali metals. An approach based on isotopic dilution, however, appears to overcome both shortcomings. The cost of removing the last traces would be sharply reduced and the entire range of separations chemistry could be applied to the design of a waste concentration system.

Consider this example. The concentration of Sr^{90} in the waste stream of a typical processing plant is 10^{-3} formal (number of gram-formula weights of solute per 1,000 ml of solution). To purify the waste so that it can be discharged from the plant site, the Sr^{90} must be reduced by 10^8. Thus if a precipitant is added that brings down 99% of the strontium, the filtrate will still require further decontamination. Merely feeding the filtrate to a second stage and adding more precipitant will, under practical conditions, precipitate only a trivial fraction of the remaining Sr^{90}. However, if the total strontium concentration is restored to 10^{-3} formal by adding a salt of natural inactive strontium, one can precipitate 99% of the total strontium in the second stage, thus reducing the Sr^{90} by another factor of 100. Using this approach, one should be able to reduce the Sr^{90} to a tolerable level at the output of the fourth stage.

Still limiting our attention to the problem of removing Sr^{90}, we can point out two potential disadvantages:

1. The cost of strontium salts, although small, is not negligible. The cost of the isotopic diluent, however, can be reduced to an insignificant amount by using cheap impure strontium salts. Indeed, in this specific case, it may be possible to use a common calcium salt as a nonisotopic diluent or carrier for the trace quantities of strontium.

2. The mass of the strontium that must be stored is four times the minimum. This fact should increase the problems of shielding, shipping and storage. Precipitates from all but the

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first stage, however, are sharply reduced in strontium content so that if they are kept apart from the carrier-free precipitate from the first stage, the shielding, shipping and storage problems are not as serious as they might appear at first glance. It is also noteworthy that the precipitated strontium would be largely free of inert salts (such as sodium nitrate) that make up the bulk of the solid concentrate from proposed waste-evaporation plants.

As mentioned earlier, the method is not limited to precipitation. It can be applied to other extractive techniques in which concentration adjustment by isotopic dilution will improve the stage separation factor.

Let us now consider the application of this method to a waste solution containing not just one radioactive nuclide but several. This is the situation one would face at a fuel-reprocessing plant or at a reactor installation that generates large volumes of low-level waste. The ideal approach is to develop a simple cascade using a single precipitant solution composed of a few inexpensive specific ingredients. A precipitate of all the radionuclides would be removed by filtration, centrifugation or froth flotation and a mixture of nonradioactive isotopic diluents would be added to the feed of each stage. Alternatively, the solution would be composed of substances that adjust the chemical conditions in the best way for efficient separation by some other extractive technique.

At this point it is difficult to determine whether or not this approach can be developed successfully and economically. Its basic simplicity and versatility, however, indicate that it is potentially superior to any competitive methods investigated or developed to date.

I should point out that this method, which involves old, well known principles of radiochemistry, has probably been considered independently by others. Indeed, looking at some of the scavenging techniques that have already been employed in waste disposal, one might even say that the principles have been applied to some extent. Nevertheless, a detailed search of the literature has not turned up a single paper that suggests or evaluates this method as a general solution to waste treatment. We are planning a more extensive analysis of the merits of this approach.

—JOSEPH SILVERMAN
Department of Chemical Engineering
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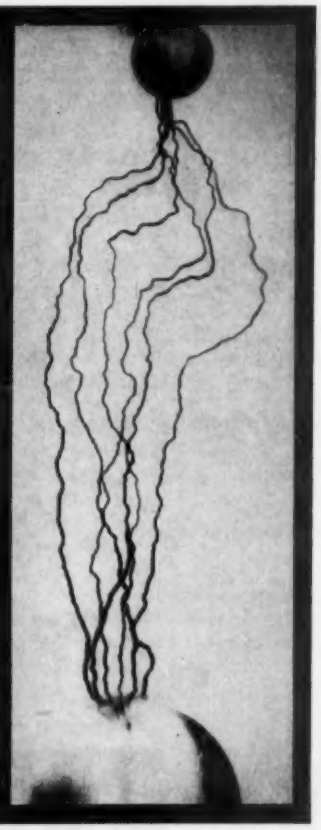

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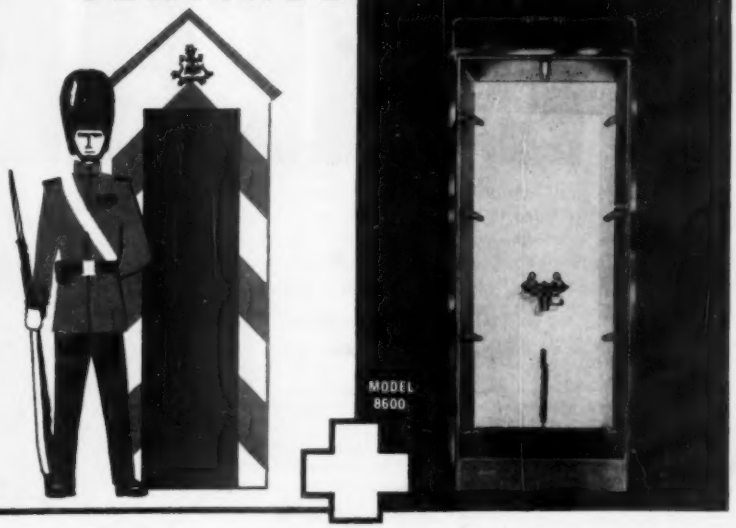

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Since the first pool reactor built at Oak Ridge to operate in the KW range, four major improvements contributing to versatility and power of pool reactors have been made. These culminated in the IRL (Industrial Reactor Laboratories) which attains 5 MW and the 15 MW ASTRA reactor in Austria, both built by AMF Atomics.

- **experimental facilities were introduced into the core**
- **forced convection of water permitted MW ratings**
- **a holdup tank was incorporated in the coolant system (IRL) to reduce water activity**
- **a layer of demineralized water was introduced to reduce surface activity (ASTRA)**

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In the PTR concept, coolant and shielding fluids (water) are in separate systems, the former pressurized and flowing through individually encapsulated elements, the latter in a separate pool water loop that cools control blades and also provides a built-in mechanism to collect leakage from the pressurized coolant system should it occur.

In addition to a unique arrangement in the core, PTR fuel elements differ markedly from standard. Tops of elements are sealed. Two-pass coolant flow is utilized in each element: coolant goes up through outside pass of each element, reverses and descends through the inner pass, all, of course, inside the element's pressure vessel. Thus, coolant flow rate is reduced.

OTHER ADVANTAGES OF PTR

PTR's prime advantage is power plus core accessibility at low cost. Here are others:

1. Existing pool reactors can be converted with minimum coolant system modifications. Two-pass flow reduces capital cost of new coolant system.

2. Fast flux irradiation space is provided in center of each element. Coolant temperature can be monitored element by element.

3. Geometry of PTR fuel makes core adaptable for in-pile loops.

4. Existing fuel element design is used.

5. Design avoids expensive reactor pressure vessels.

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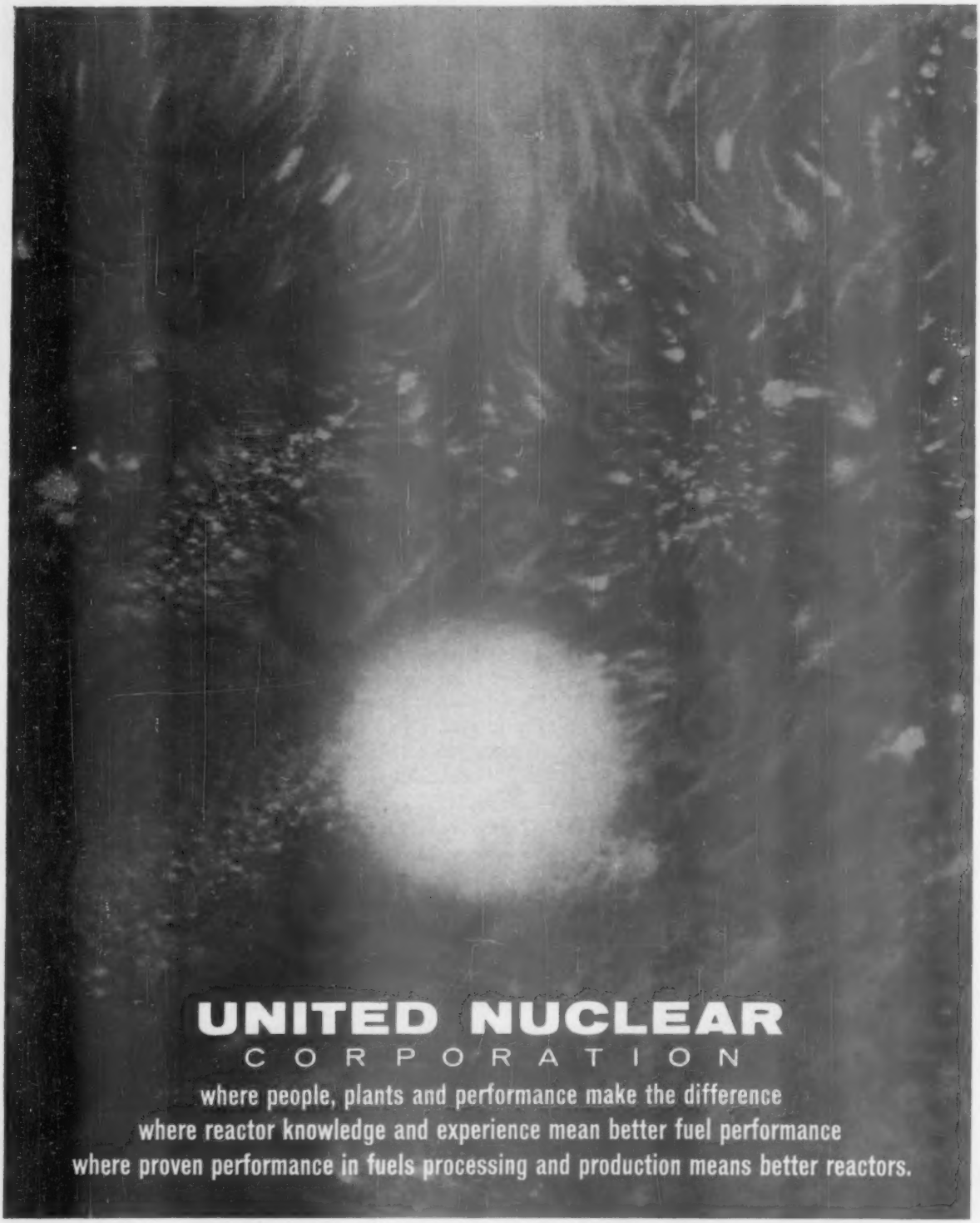
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NUCLEONICS NEWS OF THE MONTH

DOD Clears Ramjet for Engine Development, Ground Test

In a development of both military and nuclear-industry significance, the Department of the Defense (DOD) has approved acceleration of nuclear-ramjet development by AEC and the Air Force. DOD decided late in October to proceed through ground test of this unmanned, airbreathing missile, which holds out the promise of becoming a revolutionary weapons system by giving the AF a capability for delivering nuclear weapons at three times the speed of sound at ground level (NU, Aug. '60, 24).

Specifically DOD's decision gives the AF and AEC permission to develop an engine-type reactor (AEC), the engine itself (AF) and a vehicle configuration (also AF), then proceed through ground test of engine and vehicle—all of which is scheduled for completion in 1964 at a cost of at least $200-million and probably closer to $300-million. Flight test of a nuclear ramjet will probably get its first serious consideration at the Pentagon in two years, or as the budget for fiscal-year 1965 is being prepared and after AEC completes the already-scheduled tests of the engine-prototype reactor, Tory IIC.

As the program now stands it is four-phase, with the first phase almost complete:

Phase 1. Feasibility of a ramjet reactor. This was demonstrated in large part by the successful tests of Tory IIA—first in May, then in a power series in late September and early October (NU, Nov. '61, 39). Tory IIA is being dismantled for examination of the fuel elements and other components.

Phase 2. Construction and operation of Tory IIC—now expected in spring or summer of 1963—including flight controls and other engine-type instrumentation. Major technical goal of IIC is sustained reactor operation at high temperatures (greater than 3,000°F). "We just cannot be sure now that the reactor fuel elements wouldn't blow apart under such heat," according to one government official.

Phase 3. Construction and ground test of a prototype engine of operational size and weight. DOD officials expect this to entail a major test-facility construction program, presumably at the Nevada Test Site.

Phase 4. Flight test. This would come in 1965 or later.

Ramjet Funding, Management

Spending for ramjet development, beyond the current fiscal year, was still uncertain as of last month. However, AEC's current budget of $23-million was expected to rise to $50-million or more in fiscal '63; and the AF, which is spending only $7-million this year, has asked for $41-million for fiscal '63 and will probably get a substantial part of this, if not all. In approving acceleration of the program Harold Brown, assistant DOD secretary for research and engineering, left it up to the AF to decide how much money to make available, and the ramjet will have to compete with other high-priority systems in the '63 budget.

Also uncertain last month was management of the accelerated program. Following abolishment last summer of the joint AF-AEC management under Brig. Gen. Irving L. Branch (NU, Oct. '61, 20), each agency has been proceeding separately with its own responsibilities—AEC for reactor development, the AF for development of engine and vehicle. With the new urgency surrounding the ramjet, a joint office may be reestablished.

In the meantime, Irving L. Hoffman is managing reactor development at AEC, under Frank Pittman, director of reactor development, and Nelson Sievering, assistant director for advanced reactors, etc. At the AF the project has been assigned to the Advanced Technology office of Maj. Gen. M. C. Demler, who reports to the AF deputy chief-of-staff for research and technology; the present AF contracts with Ling-Temco-Vought (airframe studies and guidance system) and Marquardt Corp. (nozzle and engine-type components) are administered by the Aeronautical Systems Division, Wright-Patterson AF Base, Ohio.

Brown's office at DOD favors having Livermore, developer of the ramjet reactor, continue in this role through ground test of an engine system in 1964. Meanwhile, there is considerable industry interest in industry's coming into the program in the next 1–2 years as engine-development contractors—the same role now held by Aerojet-General Corp. and Westinghouse Astronuclear Laboratory in the nuclear-rocket program.

Nuclear Week in Chicago: Seaborg Attempts to Dispel Industry Uneasiness Over Fuels-Ownership Transition

AEC Chairman Seaborg pledged to the utility industry last month that it need have no fear of a sudden or premature switch to enforced private ownership of nuclear fuels (NU, Nov. '61, 37).

In the principle address at the annual AIF-ANS conference in Chicago, Seaborg said, "There seems to be much to commend the idea of converting eventually to private ownership. It is, of course, recognized by all concerned that a sudden imposition of a requirement for private ownership could well be a serious blow to the newly born and still insecure nuclear power industry.

"I would like to reassure you that the Commission is fully aware of this problem. If it is decided to proceed with a request for such modification of the Atomic Energy Act, we would expect to pursue this matter vigorously with Congress. But we intend that nuclear power will be an established self-sufficient industry before it will be forced to accept the full economic burden and responsibility which goes with private ownership of special nuclear material."

Then Seaborg, in a departure from his prepared text, ad libbed: "I have even heard the rumor that some who were about to embark on building nuclear power plants have dropped the idea or have been dissuaded from doing so for fear AEC would make a sudden step to embark on a program of compulsory private ownership in the near future. This is not our intention."

Returning to his text, the chairman concluded, "We would anticipate that

during the transition period, fuel would continue to be leased and unused fuel and plutonium would be credited at prices which would be consistent with their value as nuclear fuel. . . . It is important that industry, the Joint Committee on Atomic Energy, and AEC work together to assure the best interests of all concerned. We have asked for your assistance and comments on this problem and will, I assure you, continue to lean heavily on your advice."

The Seaborg talk came as the climax of a meeting that many were calling far better than the one a year ago in San Fransisco. Some pointed to the healthy attendance figures—a record 1,248 registered for ANS, with another 430 for the Forum meeting. Others took their cue from the Atom Fair, where not only nonreactor companies but reactor firms, as well, were expressing their satisfaction. Many speakers expressed the view that even the nuclear power sector is in good shape: as Chairman Seaborg put it, "I am convinced that we now have in hand technology with which we can meet our 1968 objective of competitive nuclear power in the high-fuel-cost areas."

Meanwhile, the Forum re-elected to its presidency Charles H. Weaver, vice president of Westinghouse Electric Corp; it will be his second year in the office.

Overseas Fuels Policy

A "Statement on Availability of U. S. Fuels for Power Reactors Abroad," drafted by a special Forum working group headed by Kenneth D. Nichols (former AEC General Manager, now a consultant), was submitted to the Forum meeting. The statement recommends four principles to AEC, Nichols said, in connection with AEC's re-examination of policies relating to the transfer abroad of enriched uranium for fueling the power reactors in friendly foreign countries and for assuring adequate supplies for programs in those countries under reasonable terms and conditions. The principles:

"1. Disassociate subsidy or assistance for foreign reactors from supply of special nuclear materials.

"2. Make arrangements for supply of special nuclear materials abroad as similar as possible to arrangements with U. S. industry.

"3. Simplify conditions for transfer of special nuclear materials.

"4. Provide assurance of long-term supply of special nuclear materials adequate to justify capital commitments."

Nichols said the Forum statement had been forwarded to AEC and that discussions with AEC staff "indicated AEC is considering our recommendations and has found some of our comments helpful."

National Nuclear Policy

A status report on the work of the Forum's Ad Hoc Committee on National Policy on Peaceful Atomic Energy was presented by its chairman, Chauncey Starr of Atomics International. The Committee will "shortly" be preparing its conclusions and recommendations and plans to produce its final report "in the next few months." "We have every expectation," Starr said, "that it will provide a working document for policy guidance in facing the problems of peacetime atomic energy today."

The objectives of the committee (NU, Oct. '61, 17) were to define the goals of the national nuclear program, and then to present recommendations for the methods and approaches toward accomplishment of these goals. A questionaire to Forum members, answered by 40% of those approached, is now under detailed analysis, Starr said. The Committee is seeking to assess the possible impact of atomic power on the national scene during the period 1970–2000; it will collect selected forecasts for electrical and total energy requirements in the U. S. to the year 2000, calculate the estimates of future new plant capacity additions in each region and the fraction of additions installed at various fuel prices, estimate future power costs for both nuclear and conventional plants.

'We've Lost Momentum'

Air Force Secretary Eugene H. Zuckert—a former member of AEC—told the Forum, "You will recall the enthusiasm, the great promise—and the promises—the impervious optimism and the gay confidence with which we started nearly a decade ago on a road which has turned out to be a bit rougher, steeper and longer than it looked from, say, 1952. . . . We have to face the humorless fact that we've lost momentum in the handicap race for economic nuclear power. The relays may have been run out of order for reasons, in fairness, beyond AEC's control, or regulation has outrun development. . . .

"The oil discovered in the Sahara didn't smooth the path for nuclear power in Western Europe. Neither was the path at home smoothed for American industry by the needless involvement of the developmental problem of nuclear power with the political problem of public-versus-private power—a clumsy entanglement not to be unraveled at the laboratory bench."

To Destroy SPERT I Core

Joseph A. Lieberman, AEC assistant director for nuclear safety of the Reactor Development Division, summarized once again at the Forum safety session the commission's reactor kinetics program in its SPERT (Special Power Excursion Reactor Test) series at the Idaho National Reactor Testing Station. Three reactors already in operation for some time include SPERT I, an open tank type reactor; SPERT II, a medium pressure system; and SPERT III, a fully pressurized plant capable of simulating boiling- or pressurized-water reactor plants at initial operating powers up to 60 Mw. SPERT IV, a swimming-pool type, will be started up by year's end.

Work on the effect of very short period excursions is now to be undertaken in SPERT I using an aluminum plate core, Lieberman said. Final test of the series will be a planned destructive test where a large fraction of the core will be destroyed. One of the purposes of this test is to determine the energy transfer mechanisms to the water and the nature of the steam explosion that may result, he explained. Such an all-out-to-destroy experiment has been suggested often in recent years, most recently after the SL-1 accident.

Price: Leadership in Space

A hard-hitting speech on the necessity for decisive leadership at AEC in the development of nuclear power for space was delivered on the first day by Rep. Melvin Price (D-Ill.), chairman of the Subcommittee on Research, Development and Radiation, Joint Committee on Atomic Energy. Price spoke at a luncheon session midway through an all-day session on nucleonics in space, as the Atomic Industrial Forum began its annual meeting.

The congressman tried, in effect, to get the following idea across: that AEC's nuclear-rocket and other space programs could be mismanaged as was the nuclear-airplane program or they could be made to succeed in the manner of the nuclear-naval program. "Rover [the nuclear rocket] is the third major opportunity for atomic power to serve top priority propulsion needs of our nation. First came atomic-powered submarines, then aircraft, now missiles and space vehicles. The score to date is only 50-50." He made these suggestions on how to assure the success of the rocket, SNAP (Systems for Nuclear Auxiliary Power) and nuclear-ramjet programs:

1. "Make sure that truly central

authority rests with one man. . . . That man must have full authority in fact if not in name. With him must rest the responsibility."

2. "Set a clear objective and hold it. . . . The program must go on without the interruption of schedules, funds, manpower, supplies, or facilities."

3. "Utilize AEC laboratories for . . . research and the development of experimental and prototype reactors [and], at an early stage, effect a 'marriage' between the AEC laboratory and the prime industrial contractors chosen [to develop the working systems]."

4. "Bring in qualified and competing industrial firms to tackle each identifiable and separate part of the job. After initial small educational tasks, narrow it down to those who have shown they can and will do the job."

Finger: Shoot for Moon

Harold B. Finger, chief of the AEC-NASA nuclear rocket program, told the opening session that the nuclear rocket should be considered an alternate means of reaching the moon. "I am convinced that we can design these systems . . . so that with continued development they can lead to stages that may be used operationally as the upper stages of the large chemical boost vehicles that are being considered for application in landing the first U. S. astronaut on the moon. If our technical program during this next year succeeds, then we should be able to provide an alternate approach in the lunar landing program."

In addition, more advanced work on higher-power systems to serve as secondary stages on high-thrust chemical boost stages is underway. These may provide the U. S., some day, with the capability for launching nuclear systems from the ground, Finger said. "Design work, basic-materials work, and fabrication experiments are in process to provide the technology needed in these high-power systems. From a technical point of view, the achievable power density in these advanced power reactors is as important as, or more important than, the power level itself. . . . The work aimed at developing technology of high-power-density, high-specific-impulse reactors has been included in our so-called 'Phoebus' work. This is part of the advanced reactor program being conducted by the Los Alamos Scientific Laboratory."

Berkeley Costs Down Despite Price of Learning from Calder

Now that the first of the two reactors at both Berkeley and Bradwell have gone critical, with the second to follow in a few months, British nuclear engineers are busily trying to work out their power-cost economics and to estimate what this may mean for the newer British civil power reactors still under construction.

Bids for Berkeley (138 Mwe per reactor) and Bradwell (150 Mwe per reactor) were asked well before the first Calder reactor (37 Mwe each) went critical in May 1956—and site work began only seven months later. As Calder experience accumulated, changes had to be made in the designs of the much larger Berkeley and Bradwell plants. These involved mainly fuel cans, graphite structure, control system, more core instrumentation, and thicker shielding in reactor buildings and blower houses. Together these factors delayed completion by a year and raised cost.

Total increase in Berkeley capital costs due to nuclear and other modifications—is now authoritatively estimated at $64/kw net, adding $18-million to the total cost. Whether the new figure includes any profit, or what research-development charges have been recouped, is not ascertainable. Originally both Berkeley and Bradwell were stated to be being built by the reactor-building consortia at a loss. The contractor's price for Berkeley (including the reactor, civil engineering and shielding structures, gas circuits and turbine-generator equipment) rose from $101-million in 1955 to $112-million in 1961; to this sum must be added site and site-development costs and fuel charges, bringing total capital cost today to $142.5-million, or $448/kw. Plant life has been reckoned at 20 years, but most recent British studies indicate that a 25-year life is entirely reasonable to expect. Plant load factor is figured at 75%.

Power costs have risen correspondingly from 8 to 11.2 mills/kwh due to these factors, and also to an increase in basic interest from 4.5 to 5.5% and, in the case of Berkeley, to higher fuel fabrication charges. Berkeley fuel investment is $16/kw more than Bradwell owing to the shorter and more complicated fuel-element structure, which adds 0.4 mills to the power cost as compared with Bradwell.

Nevertheless there remains a striking reduction of nearly 50% over Calder Hall capital costs thanks to economies of scale as well as those arising from the higher coolant temperatures and pressures. Sizewell, seventh power station in the British program (sixth on the England-Wales grid of the Central Electricity Generating Board, Hunterston being on the South Scotland grid) is scheduled to go on the line in 1965: it illustrates how economies due to scaling-up, site compaction and technical advances have helped to drop the over-all capital cost to $286/kw, and power costs to 7 mills/kwh. Placing both Sizewell reactors under one roof with a common pile cap (i.e. charge face, which in British reactors is on top), common control room, and common spent-fuel storage pond helped to compress the reactor site from 9 to 5 acres and to permit the Goliath crane now working at Hinkley Point to straddle the site, so it can be re-used. Compaction was also greatly helped by use of high coolant pressure, reducing the number of gas loops to four. Sizewell civil-engineering costs per kilowatt are the lowest of any station. Other major economies were effected in the turbogenerator design and use of a single universal charge-discharge machine with a standby.

Sizewell's $286/kw capital cost is a reduction from $308/kw at Dungeness. But, short of switching to concrete containment of the reactor—as Oldbury, the next station after Sizewell, will do (*see box*)—Sizewell has notched upward the major design parameters almost as far as they will go. Beyond this size—even with the adoption of hollow uranium rods, one proposed improvement—the specific costs of major reactor components tend to remain constant.

TNPG to Build Oldbury Station

Oldbury-on-Severn nuclear power station, eighth civilian power station in Britain, is expected to go to The Nuclear Power Group for construction this month when the Central Electricity Generating Board awards the contract for the 550-Mwe two-reactor plant. TNPG is already contractor for Berkeley, Bradwell and Dungeness.

Oldbury will be the first CEGB station to adopt concrete containment of the core instead of a steel pressure vessel (as predicted in NU, June '61, 25). However, it is not yet apparent whether the entire primary circuits, steam generators and all, would be contained in the concrete shell, or only the core. Most reports suggest CEGB is in fact adopting the second, less daring and ambitious —and less economic—arrangement. The French are already doing this at Chinon in EDF-3.

PM-3A and SNAP 7C Shipped to the Antarctic Together

A little nuclear history was made at Davisville, R. I., on Nov. 3, when both a reactor and a radionuclide power source were loaded aboard the Navy transport USS Arneb, *for shipment to McMurdo Sound, Antarctica. The units were: PM-3A, a 1.5-Mwe power reactor, the first of two nuclear plants to be installed at McMurdo; and SNAP 7C, a 10-watt, strontium-90 generator that will power an unmanned weather station at a site 400-mi northeast of McMurdo. Both were built by Martin Co. under contract to AEC and both are scheduled for operation by early in 1962. The stories on this page discuss the outlook for these two types of power sources.*

Small-Reactor Outlook Still Cloudy

The remote-reactor outlook is still bedeviled by the frustrating annual-budget problem at the Pentagon, which has put the military customer for small stationary or mobile reactors into the position of having to say: "Yes, nuclear plants might be as cheap or cheaper than conventional plants at some places over their lifetime—and easier to supply with fuel—but their higher first costs would take budget dollars away from other projects we would like to have."

Nevertheless, this budget obstacle (NU, Apr. '61, 27) appears to be giving way gradually to: 1. constantly improving reactor economics and technology; and 2. the rising nuclear-war tension, which, in forcing the military to go underground, leads the services to look more sympathetically on power plants which could be operated easily at buried installations. With all factors considered, orders for small reactors are expected to continue sporadic for another two years, not reaching the several-per-year stage before 1964 or 1965.

MILITARY REACTOR STAFFS

In the last year, all three services—Army, Air Force and Navy—have completed the staffing of groups qualified to review and monitor stationary (or mobile) reactor projects. In each case, their thinking is dominated now by the desire to get operating experience on plants already built or ordered (Army: PM-2A in Greenland, SM-1A in Alaska, and ML-1 in Idaho; AF: PM-1 in Wyoming; and Navy: PM-3A at McMurdo and PL-3 at Byrd Station).

Army. Engineer Corps officials feel that a hard-site (underground) reactor may be ordered in the next year, barring an adverse development in military reactors now in use; location of the most likely site could not be revealed. In addition, there are requirements for the compact ML-1-type, gas-cooled power plants; the first field unit has been budgeted (ML-1A) but this and others of the type would not be ordered before next spring, when there should be some operating experience on ML-1. Meanwhile, the Army will carry out an up-to-date study of its overall nuclear-power requirements.

Air Force. The AF program for small reactors—with the accent on air-transportable plants—is managed jointly by the Air Force Systems Command and the Directorate of Civil Engineering, with a group at the AF Special Weapons Center, Albuquerque, N. M., also active in nuclear-power consideration. AF officials foresee a substantial demand for reactors for hard missile sites if PM-1 operates well at Sundance AF Base, Wyo.

Navy. Again, in the vein "Let's see how those we have operate," the Navy would like to have some PM-3A experience before getting into large-scale purchases. However, a second reactor is on order for Antarctica (PL-3) for shipment to Byrd Station by Alco Products, in late 1963. Navy plans also include: a second reactor at McMurdo, a PL-3-type plant at the South Pole, and a 20-Mwe plant for Guam ("It is hoped that the Bureau of the Budget will permit a joint funding arrangement with AEC in order to proceed with a . . . plant for Guam.").

REACTOR DEVELOPMENT AT AEC

The several-year-old Army Nuclear Power Program, from which all existing small military reactors have flowed, is undergoing a metamorphosis from its original charter (a varied family of reactors up to 40 Mwe) to one emphasizing plants no larger than 5 Mwe, plus systems for special applications. At the same time, the Army Reactors group at AEC is concentrating on the reduction of construction and operating costs of existing systems and on improving their reliability.

The group has one contractor working on the feasibility of mobile nuclear energy depots (NU, Apr. '61, 24) and other studies are planned; the aim is to couple nuclear heat with prospective techniques for propelling military vehicles (fuel cells, chemical batteries, etc.). Small reactors are also getting some consideration as emergency

SITES OF PM-3A, SNAP 7C, respectively: McMurdo and Little America V

SNAP 7C GENERATOR ready for shipment to Davisville, R. I., dock

PM-3A REACTOR VESSEL just before loading aboard Navy Transport Arneb

power sources after a nuclear attack. The new civil-defense staff at the Defense Department has gotten data on small reactors from AEC but DOD officials say they must get well into an expensive program of fallout-shelter construction before they look seriously at nuclear power.

An industry official perhaps best summed up the status of small reactors for the military, when he said in effect: "Small reactors are not now economic anywhere except in the Antarctic. Meanwhile, they have not yet proven to be reliable power sources. At any price, the military is not going to buy on a large scale until they are convinced that the plants are reliable."

Radionuclide Power Growing Fast

When SNAP 7C goes into service shortly after Jan. 1 to power unmanned weather instruments 400 mi from McMurdo, it will be the fourth radionuclide power generator to go into service since June—a plutonium-238 device was launched with the Navy's Transit IV-A in June; this was followed in August by a strontium-90, weather-station unit in the Canadian Arctic (NU, Aug. '61, 25); and, before Christmas, the U. S. Coast Guard is expected to be operating SNAP 7A, a 5-watt strontium-90 system for a flashing-light buoy in Chesapeake Bay. All of these were built by Martin Co.

Then, during 1962, the following radionuclide generators are to go into service: early in the year, a 5-watt, cesium-137 system built by Royal Research Corp. to power seismographic instruments on the floor of the Atlantic Ocean (NU, Sept. '61, 26); next summer, a 30-watt Martin system to power weather instruments on a hurricane-tracking boat in the Gulf of Mexico (SNAP 7D); and early next fall, a Martin 30-watt strontium-90 system to power a 250-watt flashing-light beacon of the Coast Guard (SNAP 7B).

Moreover, these seven generators may be joined during the year by: one or more Pu-238 sources for operational Transit satellites; and prototype generators for applications either classified or not yet firmed up. These include undersea warfare uses and other commercial, military and outer-space applications.

The market for radionuclide generators can be divided roughly into two areas: those military and space applications where capability and reliability will be considered more important than economics; and government and commercial applications where economics will be given more emphasis. The Navy's Transit navigational satellites, for example, are being designed to operate for at least five years, preferably more. A long-lived radioisotope like Pu-238 is the only heat source available with anything like a 5-year-lifetime capability.

On the other hand, radionuclide generators are and will be competing with other sources of power in such commercial applications as communications satellites. Here, although there is an awareness of radionuclide power, there is a disposition to stay with solar-cell power as long as it will do the job.

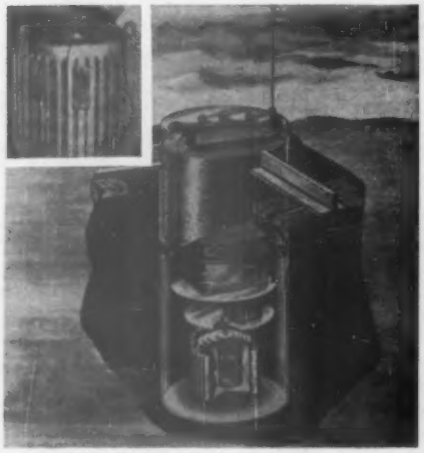
COST, SUPPLY BIG FACTORS

Thus, many government and industry officials consider the largest obstacle to rapid and widespread application of nuclide power to be cost—and, close behind cost, the related factor, supply. For fission products like Sr-90, Cs-137, cerium-144 and promethium-147 it is generally agreed that a sizeable increase in production would bring a corresponding drop in cost. Estimates for reducing the prices of Sr-90 and Cs-137 have run as much as 75–90%, once multi-megacurie separations capacity has been established. AEC is in the process of building a pilot-plant for testing large-scale separations techniques; and it has said that it will expand the pilot-plant's capacity in the next 12–18 months, unless it gets a feasible proposal from industry to do the job (NU, Oct. '61, 21). The only question of fission-product supply remaining as of now is: Will it be increased fast enough and substantially enough to meet the demand for remote land, sea and undersea generators?

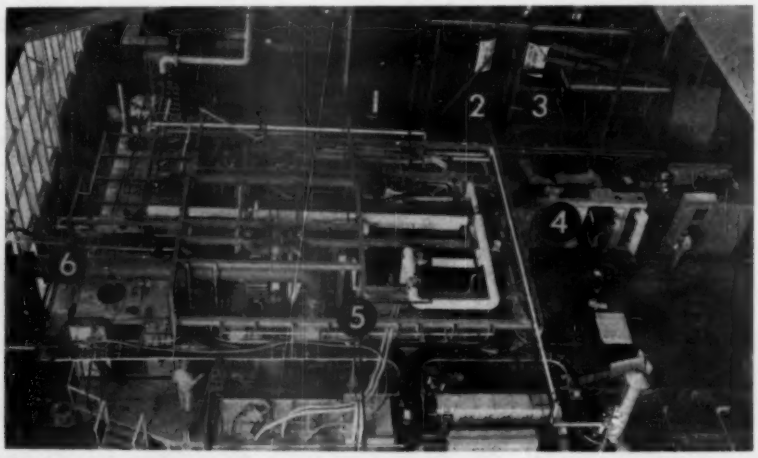
The supply—and, only incidentally, cost—question is also a factor in outer-space uses of nuclide generators. Here the supply problem is more acute because transuranium elements, such as Pu-238 (87-yr half-life) and curium-242 (163-day half-life), are the most feasible heat sources and they must be especially produced. The whole story on Pu-238 is not known because, as a by-product of weapons-material production, its production is classified; however, industry and government officials have made it clear in recent months that Pu-238 is in short supply in terms of possible uses in space.

Cm-242 generators will first be used in NASA's Surveyor series of soft-lunar spacecraft landings to gather lunar environmental data (NU, Oct. '61, 28). There are other missions of up to six months for which Cm generators could provide the power but, again, supply will be a major consideration in these.

Other radioisotopes under serious consideration for land, sea or space power generation are cobalt-60, promethium-147 and curium-244 and mixed fission products. All of these require some developmental work.



SNAP-POWERED WEATHER STATION will be buried in ice



PM-3A LAID OUT as it will operate: 1, steam generator; 2, reactor vessel; 3, spent-fuel tank; 4, control panel; 5, turbogenerator; 6, line to condensers

Italy's Three Full-scale Reactors to Make 525 Mwe by 1964

Italy's ambitious nuclear power program—three reactors with an initial output of 525 Mwe (ultimately 625 Mwe with core improvements)—is on schedule.

While the U. S., British and French nuclear power programs were getting more of the limelight, the Italians have been at work on projects more frequently reported individually than as part of a national effort. The program is a well-balanced one, comprising one pressurized-water, one boiling-water and one Calder-type gas-cooled reactor. And with the Italians working closely with the most experienced reactor manufacturers in the U. S. and Britain, no major delays have been encountered so far and all three reactors are on schedule, with the last to be completed within two years.

Two of the three—the two water reactors—are being built by U. S. firms: Westinghouse the 165-Mwe Yankee-type reactor for SELNI, and General Electric the 160-Mwe Dresden-type unit for SENN. The Nuclear Power Group of Britain is building the 200-Mwe gas-cooled reactor for SIMEA. Here is where each stood last month:

SIMEA

SIMEA: Società Italiana Meridionale Energia Atomica = Southern Italian Atomic Energy Company

At Latina, where a subsidiary of the state-owned ENI gas and oil complex, SIMEA, is building its British-type reactor (actually a single, scaled-up Bradwell reactor), testing of the carbon-dioxide blowers has just started. Inside cleaning of the 72.2-ft-diameter, spherical steel pressure vessel was recently completed and stacking of the graphite moderator within it will soon get underway. Meanwhile laying of the carbon-dioxide pipeline network and fuel standpipes continues. Work on the second group of vertical steam generators outside the reactor building is nearing completion. Assembly of external fixtures and main water and steam pipelines between reactor and turbine hall is in progress; construction of the spent-fuel cooling pond is well advanced.

In the turbine-generator building, installation of the first of three turbogenerator sets is completed, the second is nearing completion, and foundation plates for the third are laid. Work is underway in the control room on the centralized control panel and plant instrumentation. Also well along are the laboratories annexed to the nuclear power plant, and the seawater condenser cooling system. Some of the auxiliary plants are already in the testing stage. Criticality is due end-'62.

An agreement was reached recently with the U. K. Atomic Energy Authority covering supply of the first 400 tons of natural uranium fuel slugs for Latina (one loading requires 262.5 tons). Price, not disclosed, is unofficially estimated at about $15-million.

SENN

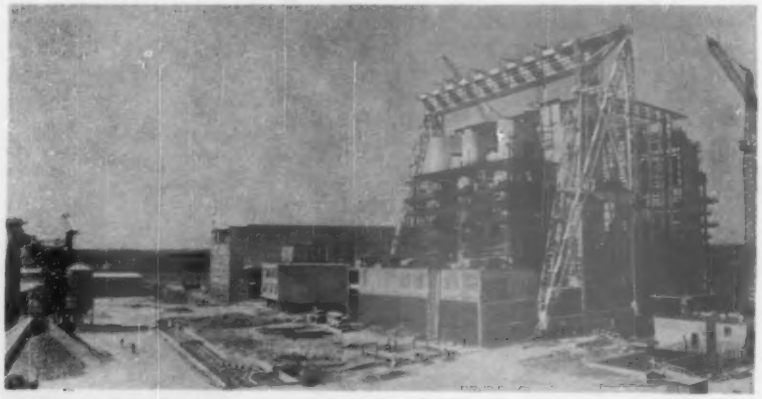
SENN: Società Elettronucleare Nazionale = National Electro-Nuclear Company

The nuclear power plant rising at the mouth of the Garigliano river for the SENN utility group is 50% complete. The 164-ft-diameter steel containment sphere that will house the reactor has been completed and successfully pressure-tested. Work on supporting structures inside the sphere continues. The nuclear end of the plant is just coming out of the design stage and entering the construction stage: core design is just about complete; control circuit and cooling circuit design are almost completed.

SENN has already ordered fabrication of the zircaloy-2 cladding and of enriched uranium-oxide powder, the former from Reactive Metals, Inc., and the latter from Fuels div., United Nuclear. Final assembly and weld-sealing of the fuel rods will be done at GE's San Jose fuel-fabrication plant. Deliveries have begun by AEC of enriched uranium, as fluoride, for conversion to oxide, and the first samples of uranium-dioxide powder have been delivered to GE's Atomic Power Equipment Dept. for testing and making sample pellets. Mass production of the fuel is expected to start shortly. Design work on the control rods is completed (they will be the new Dresden type using compacted boron powder in thin tubes within the blades of the cruciform control rods). Prototype control-rod drive mechanisms have been built.

The turbogenerator building and its annexed control room were completed last month. Auxiliary buildings have been ready for some time; for example, the radioactive discharge building and the building housing the plant for cooling-water intake from the Garigliano river are awaiting installation of equipment. The 328-ft exhaust stack is almost topped off, and the switchyard foundations are completed. Fabrication of power and mechanical equipment is in its final phases at the shops of the subcontractors, and flow of delivery to the

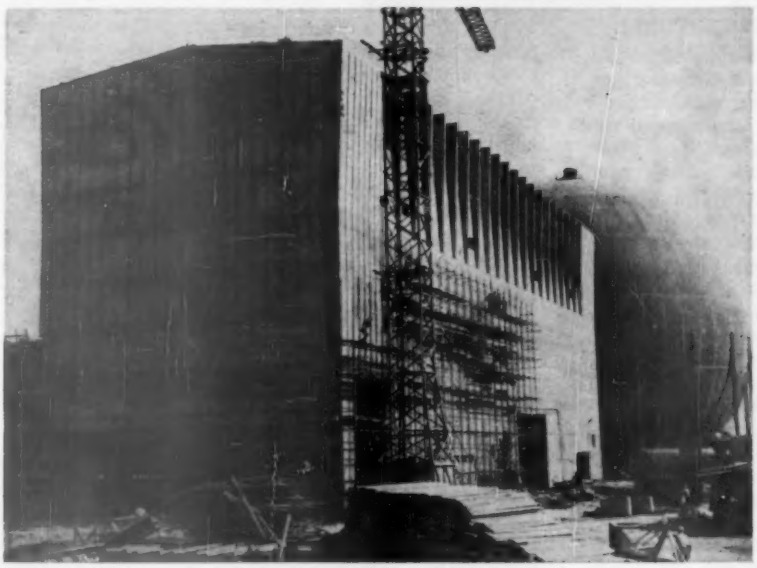
1. SIMEA: Bradwell-type Reactor Due for Criticality at End of 1962



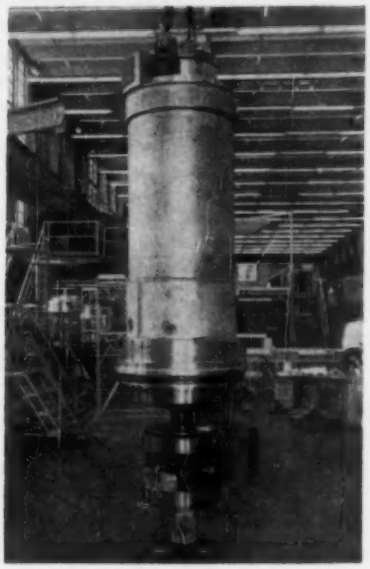
CLOSEST TO COMPLETION of Italy's three big power plants, the British-built gas-cooled reactor rises above the wartime Anzio beachhead at Latina

STANDPIPES for charging and discharging fuel (compare foldout p. 37)

2. SENN: Dresden-type Reactor Has Criticality Scheduled Early in 1963



TURBINE-GENERATOR BUILDING and (background) the reactor containment sphere loom above Garigliano river, also familiar to U. S. troops in World War II



MOTOR IMPELLER by GE for a SENN canned main coolant recirculating pump

site for assembly is beginning this month.

Preliminary systems testing is scheduled for the end of 1962. Fuel loading and final plant checkout are to follow immediately, with criticality scheduled for early 1963.

SELNI

SELNI: Società Elettronucleare Italiana = Italian Electro-Nuclear Company

Design is almost completed, and fabrication of all primary components except the core will be completed this year or early next year for SELNI's privately-financed reactor (SENN and SIMEA are financed from governmental funds, SENN with the aid of a World Bank loan. SELNI has a $34-million Export-Import Bank loan). The reactor pressure-vessel, just completed at Combustion Engineering's Chattanooga, Tenn., shops, will be pressure-tested at 3,750 psia (operating pressure 2,500 psia) before the year is out. The four 24,500-gpm canned rotor primary coolant pumps, built by Westinghouse, will also be tested this year.

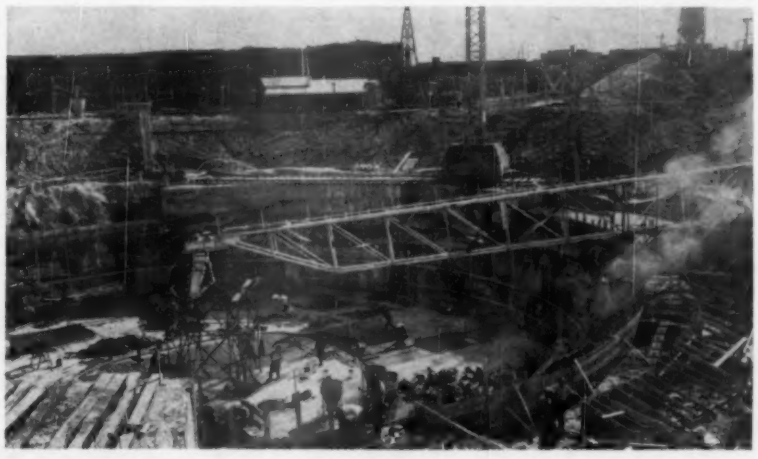
The four steam generators are due for completion at the beginning of 1962, and the control-rod drive mechanisms in mid-1962. All other nuclear components are to be delivered to the site in the first six months of next year. The core—oxide pellets in tubes, like SENN, but with the tubes of stainless steel—will be fabricated by Westinghouse at its Cheswick fuel plant. Italy's Franco Tosi company is building the 180-Mw turbine-generator set and condenser, and is about halfway along.

At the plant site at Trino, on the Po river between Milan and Turin, levelling of ground for the plant over an area of 1.4-million ft² is almost completed; foundation digging for the reactor is finished and concrete pouring is underway.

Completion of construction and mechanical assembly of the nuclear plant is scheduled for September 1963, with criticality to follow by end-'63.

The reactor's initial 165-Mwe output is an increase from the 134-Mwe of Yankee, of which SELNI was originally to be a "Chinese copy." It is achieved by changes in the size and design of the core: a three-region core of concentric rings, with enrichment varying from 2.6 to 2.8%, will be used. By the time all three rings have been refueled once, the reactor is expected to reach 225 Mwe. An additional 85-Mw turbine is slated to take care of electricity generation above 180 Mw; present plans are for the reactor to go on the line with both turbines if technology is sufficiently advanced. If not, the second turbine would be installed later. SELNI says it does not know when core improvements will permit the plant to put out the maximum 265 Mwe using both turbines.

3. SELNI: Yankee-type to Start Up at End 1963



FOUNDATIONS being laid for the SELNI reactor vapor container, in north Italy on the Po river. This was state of progress on Oct. 11, 1961

REACTOR NEWS

PWR REFUELED AGAIN; 4TH SEED POSSIBLE

Shippingport's second refueling was completed ahead of schedule—in 44 working days, as against the 53 that had been allotted. The first refueling required 117 working days. Begun Aug. 16, 1961, the second refueling of the nation's first full-scale nuclear power plant was completed Oct. 6; the reactor went critical again Oct. 7, and started producing power again at 3:15 a.m. Monday, Oct. 23. Performance has been outrunning design expectations by increasing margins: the first blanket was expected to last only two seed lifetimes for a total of 8,000 hours design life, but actually logged 13,707 full-power hours on the first two seeds (5,806 actual against 3,000 designed hours on the first, 7,901 actual against 5,000 designed hours on the second seed). The second seed maintained a plant load factor of 70% over its operation from May 7, 1960, to Aug. 15, 1961. Not only has a third seed now been installed, but a fourth seed is now being fabricated in the expectation that the blanket may well have still further life left after the third seed is burned out. Duquesne Light Co., operator for AEC of the pioneer pressurized water plant, reports that on three occasions in the last ten months PWR ran for more than 1,300 continuous hours at full power, generating about 700 million kwh each time.

EBR-2 RUNNING 'DRY CRITICAL'

AEC's Experimental Breeder Reactor No. 2 is performing satisfactorily in physics tests being conducted with the reactor "dry critical"—that is, without sodium coolant and at negligible power. Fifth and last to be completed of AEC's 1954 five-year reactor program, EBR-2 first went dry-critical without fanfare Sept. 30, hitting predicted calculations almost on the nose (criticality was reached with 87 elements, as against 85 predicted). In addition to the physics testing work, the daily dry-critical experiments are permitting check-out of the fuel-handling mechanisms, instrumentation and other systems, which are working smoothly. On the secondary side some piping has had to be disassembled for cleaning and is now being reassembled. The dry criticals were completed early in November, the core was unloaded, and about two months of work begun preparatory to filling the primary and secondary systems with sodium. "Wet criticality" with sodium flow is not expected until March or April of 1962.

GODWIN QUITS: *SAVANNAH* FUELING NEAR

Richard P. Godwin, head of U. S. nuclear merchant-ship program since 1957, has resigned government service and gone to work for Bechtel Corp. in San Francisco. He has held a "two-hat" position as head of AEC's Maritime Reactors Branch and head of the Maritime Administration's Nuclear Projects section (recently he had been promoted at MA to head its Office of Research and Development with cognizance also over all nonnuclear advance work). In charge of the *Savannah* project since its inception, as well as longer-range nuclear propulsion programs such as the Maritime Gas-Cooled Reactor, Godwin had recently also been leading development work in other areas, many of them potential applications for nuclear power such as hydrofoil and surface-effects vessels, mechanized and automated ships, etc. (NU Wk, 5 Oct. '61, 3). At Bechtel Godwin will work under W. Kenneth Davis, his former chief in AEC's Reactor Development Division. E. Kemper Sullivan has been named acting head of MRB by AEC and Marad . . . Meanwhile, AEC permission for NS *Savannah* to load fuel was expected momentarily. The ship was put through a two-day dress rehearsal of the fueling process using dummy elements Nov. 8–9, and the 32 live elements were transferred from dockside vaults to the ship's No. 4 hold in readiness and for fueling. Actual loading awaited final approval of AEC's regulatory staff. Meanwhile the required change of control-rod components made of 17-4-PH steel treated at 900°F to ones treated at 1110°F has been carried out; precritical tests of the control-rod drives will now be made after fueling. Thereafter low-power tests, to 10% of full power, will be carried out at dockside at Camden, N. J., before *Savannah* goes on non-nuclear power to her Yorktown, Va., power-range test base.

ENTERPRISE GOES TO SEA

USS *Enterprise*—biggest ship in history, the Navy's second nuclear surface ship, driven by the world's biggest operating nuclear powerplant—went to sea for the first

time Sunday, Oct. 29, for six days of preliminary acceptance tests of her propulsion, electrical, hull-machinery, electronics, aviation, ordnance and other systems. William E. Blewett, president of Newport News Shipbuilding & Dry Dock Co. which built the $450-million ship, told NUCLEONICS that she "performed perfectly" in all respects in completing her propulsion tests including a 4-hr full-speed endurance run, steering, backing, and going from full-speed ahead to emergency astern; she developed full design power and "exceeded all our expectations." The 86,000-ton, 1,101-ft flattop—with a complement of 4,600—has a 280,000 hp Westinghouse pressurized-water reactor powerplant (210 Mwe equivalent). She will be commissioned and turned over to the Navy Nov. 25—more than two months ahead of contract date.

MARQUARDT CUTS BACK NUCLEAR STAFF

Marquardt Corp. has disbanded its Nuclear Systems Division and reorganized its nuclear activities on a more modest footing. Former division director Alan R. Gruber has left the firm; his former projects have been split in two sections: Project Pluto (nuclear ramjet) work still Marquardt's biggest nuclear project, is now in the Propulsion Systems Division, while work on stationary reactors is concentrated on a 12-man Nuclear Research Dept. placed under the ASTRO (Aero Space Technology Research Operation) Division. On Project Pluto, while Marquardt is continuing to do reactor component development work—especially instrumentation and controls, and nozzles—it is setting its sights more on the engine side than the reactor side of the ramjet propulsion package. On stationary reactors, the organic DCDR project (Direct Cycle Diphenyl Reactor: NU, Dec. '60, 31) is continuing, still company-funded.

WORLD NEWS

Food-Irradiation Programs Gain Momentum

A decision by Canada's Directorate of Food and Drugs to permit irradiation of potatoes (NU, July '61, 26) apparently has increased international interest in food irradiation. Irradiation of fruit juices, potatoes, eggs and grain, reported either in progress or in planning at an ENEA (European Nuclear Energy Agency) food-irradiation study-group meeting in Paris late this fall, indicates a growing wave of interest in the process. One delegation, the Austrian, proposed an international project calling for use of a 120,000-curie source at a semi-industrial plant to supply 200,000-rad doses to irradiate an estimated 20,000 pints of fruit juice a day. The plant would be backed up with a research program to determine optium doses, storage problems, influence of irradiation on vitamin content, and effective wholesomeness testing. The Austrians currently are working on fruit-juice irradiation at the Seibersdorf Research Center, near Vienna. Food-irradiation experts from other countries believe that the program would have to be expanded to additional products to make it attractive to other nations.

French clearance. In another development, French potato-irradiation sponsors have decided to seek government clearance for their process late this year or in early 1962. Although French potato-irradiation technology is at the pilot-plant stage (NU, June '61, 23), formidable administrative barriers lie between irradiated potatoes and the market. However, Canadian clearance of irradiated potatoes for human consumption has undoubtedly encouraged Conservatome, the French potato-irradiation group headed by Pierre Vidal.

Atomic Energy of Canada, Ltd., meanwhile, announced plans to irradiate 1-million lb of potatoes this year. The Canadians started on-the-spot irradiation at harvest points in late October, using a $125,000 mobile unit equipped with a cobalt-60 source of 80,000 curies arranged on a line on a 50-in. rod. (The cobalt-60 source and a dose limit of 10,000 rads were prescribed by Canada's Food and Drugs Directorate.) The Canadians reported that the process, capable of irradiating 2,900 lb/hr, was competitive with chemical preservation methods.

British program. In still another ENEA development, British researchers from Wantage and the Cambridge Low Temperature Research Station reported that they are using 500,000 rad doses from their cobalt-60 source to kill salmonella bacteria in frozen whole eggs (NU, Wk, 2 Nov. '61, 5). They said a 600,000 source—operating continuously—would be necessary to sterilize 12,000 tons annually. (Annual British consumption: 30,000 tons.) However, at least five years to complete feeding experiments and obtain medical approval would have to precede a decision to market the eggs.

Another British report, on grain disinfestation in Australia using a cobalt-60 source, described the process as economically infeasible because it would require 1–2-million curies. However, it said that particle-accelerator irradiation "looks competitive." ENEA is querying grain-importing countries to determine their reaction to grain disinfestation by irradiation. ENEA also plans to publish a 'state-of-the-art' roundup based on all reports presented at the meeting.

ENEA for Common U. S.-European Research

A transatlantic program of advanced research was proposed in a meeting of the European Nuclear Energy Agency last month attended by 15 Western countries including the U. S. and Canada. One of the proposals made in a report by Lew Kowarski, ENEA's scientific adviser, could lead to international teams of researchers working on U. S., Canadian or European advanced-reactor projects. ENEA's top-level experts—for the most part heads or research chiefs of national atomic energy commissions—generally agreed that the international-team approach had merit, but felt that more preliminary talks were needed prior to establishment of a definite proposal. U. S. and Canadian delegates reacted favorably to the idea, NUCLEONICS learned. Three other Kowarski suggestions deemed worthy of further study were: 1. arranging for all-European access to a reactor with a flux of 10^{15} or higher; 2. establishment of a reactor physics committee along lines recommended by the European-American nuclear data committee, to coordinate general studies of steady states and low-power kinetics in chain-reacting media; 3. to set up international cooperation in research on direct conversion—specifically thermionics and magnetohydrodynamics.

Germany to Order Nuclear Merchantman

An order for construction of Germany's first nuclear merchant ship—the world's second—is expected to be placed next summer with the Howaldt shipyard in Kiel. Official placing of the long-awaited order from the Association for Nuclear Energy Utilization in Shipbuilding and Shipping (GKSS) in Hamburg (NU, Mar. '61, 32), must await working out of detailed specifications by GKSS, to be completed by the end of this year; then Howaldt may have to make some design adjustments to meet the specifications.

Construction of the $10-million, 15,000-ton bulk carrier, which will be propelled by a 10–11,000-shp organic moderated reactor plant to be built by Interatom, is scheduled to start late in '62 for completion by 1964–5. Among the design details are a reactor plant refueling cask for autonomous replacement of fuel elements, as well as facilities to store used or damaged fuel elements aboard in safety. Replacement of the reactor has been provided for in the design which permits cutting out of the entire hull section housing the reactor. The *Savannah*-size research vessel, which will accommodate 75 crew members and 35 guests, is not expected to operate economically.

Euratom contract. In a related development, Euratom signed a research contract with GKSS in late October as part of a five-year international nuclear ship research program (NU, Jan. '61, 24) toward which Euratom will provide $1.7-million. The new contract covers improvement in mechanical strength of ship-reactor components, particularly fuel elements and control rods, under acceleration forces caused by ship movements.

First USSR Nuclear Sub Now Operational

Reports from a number of Russian newspapers indicate that Russia is now operating at least one nuclear submarine. The reports claim that the Russians have the world's fastest "fleet" of nuclear submarines. Although Russia has been reported for at least four years to be building nuclear submarines, only these most recent reports have included alleged eyewitness accounts. One story, in Izvestia, obliquely described the power plants as providing 2,000 times the "capacity to run" a submarine with diesels and batteries. Meanwhile, the Russian nuclear-powered icebreaker *Lenin* made her second cruise across Arctic ship lanes, according to a Tass (Soviet news agency) report.

NEWS IN BRIEF

AEC Postpones Reactor-Incentive Program

AEC has shelved for at least a year the consideration of possible new incentives to encourage construction of power reactors. Reason, according to AEC sources: the unfavorable mood created in Washington over proposed generators for the Hanford New Production Reactor (NU, Oct. '61, 17). The AEC staff had almost completed its work on possible incentives when the NPR fight reached its peak; then, at the Commission level, it was decided to drop the project—at least this year. AEC Chairman Seaborg had said earlier (NU, June '61, 17) that AEC was reviewing the entire reactor-construction situation and, "if we determine that financial incentives can give us the program we need to move ahead toward our national objectives, we will make appropriate proposals to the Congress (early in 1962) as part of our fiscal-year 1963 authorization request."

AEC Adopts Conflict-of-Interest Regulation

A new regulation barring ex-AEC employees from getting AEC business for two years after they leave the Commission has been adopted by AEC. Principal effect of the conflict-of-interest regulation will be to restrain present AEC employees from doing business with some former AEC employees. In certain cases, however, an affidavit filed with the general manager stating areas where ex-employees had exercised control and responsibility over AEC matters will allow them to come before the Commission. But AEC business can be solicited by these now privately-employed former employees only in areas outside their former jurisdiction.

The new regulation closely follows a suggestion made two years ago by Sen. Clinton P. Anderson (D-N. M.), former JCAE chairman, who was upset by the departure of high Commission staffers for high-paying jobs with nuclear industry.

The five-man Commission considered several versions of the regulation this fall. One result of their deliberation was reduction of the period during which ex-employees will be refused Commission contract business from four to two years. There was also discussion on whether scientific and engineering personnel should be exempted. Despite arguments that, if they were not, the job of recruiting highly-qualified technical personnel for AEC posts would become adversely affected, the Commission decided to include them in the regulation coverage.

First Plowshare Shot to Be Set Off This Month

A 5-kiloton fission device, the first nuclear explosion ("Project Gnome") in Project Plowshare, AEC's program to develop peaceful uses for nuclear explosives, will be detonated Dec. 10, in a salt cavern 25 miles southeast of Carlsbad, N. M. The shot, which will be set off by AEC in a completely-contained 1,116 ft long horizontal tunnel 1,200 ft underground, will be used in an attempt to determine: 1. the possibility of using stored heat for electrical production; 2. the possibility of producing radioisotopes (e.g., plutonium-238 used in Transit IV-A); 3. measurements of neutron production; and 4. the amount and kind of rock crushed by such a device. AEC hopes to drill holes down into the salt and circulate water or another coolant through it to bring heat to the surface for steam production.

Meanwhile, two significant developments since nuclear-weapons test resumption have added impetus to Plowshare: 1. Congress increased its budget for this fiscal year from $8.5-million to $8.9-million—Project Gnome will cost about $5.5-million, including approximately $500,000 for the explosive device—and; 2. AEC, in reorganizing, gave the former Plowshare branch of the Military Applications Division full divisional status, under John S. Kelly.

Rauth Out—and Up, Bennett In at Martin Nuclear

Ralph D. Bennett has been appointed vice president in charge of Martin Co.'s Nuclear Division. The 61-year-old Bennett, formerly manager of General Electric's Vallecitos Atomic Laboratory in Pleasanton, Calif., had been Martin's director of research since last January. He replaces J. Donald Rauth, who has been named to the newly created post of director-coordinator of all Martin ICBM and space booster programs. Since Rauth became general manager of the division in 1958, Martin has risen to a position of prominence in the nuclear industry.

Rauth

Bennett

Opposition Mounting to Regulatory Transfer

State and industry comments filed with AEC during recent weeks indicate growing opposition to AEC's proposed regulation that would permit transfer of nuclear regulatory authority to the states. The opposition currently is centered around two controversial provisions of the amendment: control over land disposal of radioactive wastes, and intrastate transfer of manufactured items containing radioactive materials. The controversy has jeopardized a pending agreement, under terms of the proposed regulation, that would permit Kentucky to assume regulatory authority (NU, Oct. '61, 26). Kentucky had assumed it would have authority over these areas but AEC has withheld a decision, pending comments from the public.

It was principally on these two issues that the Southern Governors Conference went on record this fall opposing AEC's transfer policy. Specifically, the 16 states represented—including Kentucky—want qualified states to assume jurisdiction in both areas. The conference contends that the proposed AEC regulation would create a system of dual government administration over the same licensees, and would impair both the development of confidence in the states and in the radiation regulatory programs they are developing.

Unfavorable comments. Other recent objections either to the pending AEC-Kentucky agreement or directly to proposed regulation itself—or to both—have been raised by the following states: New York (NU Wk, 2 Nov. '61, 6), Michigan, Oregon, Colorado, Tennessee and South Dakota. In addition, objections have been received by AEC from several industry firms who would be affected. In general, both industry and the states concur with the Southern Governors' argument and also see probable conflicts arising from differing regulations that various states would be empowered to enact.

Meanwhile, the Atomic Industrial Forum, through its Federal-State Relations Committee, has been conducting a continuing study to determine if the proposed regulation can provide a practical working arrangement. A compromise under study at AEC would involve Federal-State reciprocity on regulation, so that a given company would not be licensed twice for the same activity.

RADIATION NEWS

Anton Heads New Nuclear-Instrument Firm

A new nuclear-instrument firm has been founded by Nicholas Anton, former president of Anton Laboratories (now Lionel Laboratories—NU Wk, 1 June '61, 4). Co-founder is Myron Youdin, former Anton vice president. The new company, Eon Corp., has filed a registration certificate with the Securities and Exchange Commission covering the proposed sale of 133,333 shares of common stock to raise about $1-million. Eon's initials stand for electronic, optical and nuclear—the three areas in which the firm will market instruments. First instrument production is not scheduled until after Jan. 1. In the prospectus, Eon said it planned to produce "an advanced line of radiation detection instrumentation and radiation detectors for use in civilian defense, health physics and medical isotopic diagnosis and research. Other proposed products are instrumentation such as linear and logarithmic amplifiers and period and rate meters and detectors such as proportional counters, solid state and liquid detectors and photon counters, for the oil well logging and nuclear power field. The company also expects to apply for government research and development contracts." More specifically, Eon's plans include medical instruments using radionuclides; nonnuclear medical instrumentation; and a "complete line" of detection instruments—including solid-state semiconductor-type detector—which "copies nobody."

HVEC, Victoreen 'Informal' Partners . . .

High Voltage Engineering and Victoreen Instrument have worked out an informal association to market a "package" concept in neutron activation analysis for those doing routine analyses, rather than research—for example, such things as analyzing batches from a production stream and routine laboratory analyses. Between them, the two firms would supply a complete activation-analysis system: HVEC supplying one of its Van de Graaff accelerators up to 3 Mev, associated neutron targets, sample-handling equipment and neutron-shielding and -moderation equipment. Victoreen would furnish detection, data-processing and display equipment. In most cases, the customer would deal with HVEC, as the accelerator manufacturer; HVEC would routinely specify Victoreen equipment unless the customer indicated a preference for something else. The arrangement is non-exclusive.

. . . 2 Others Reach a Formal Arrangement . . .

Nuclear Industries, Inc., has reached a marketing/financial agreement with Digital Dynamics, Inc., Culver City, Calif., whereby DDI will get an undisclosed amount of capital; there will be an exchange of stock between the two firms; and NI will market all DDI products, which include: 1. a nuclear events dynamic analyzer (NEDA) for rapid analysis of blood circulatory phenomena in coronary, cardiac, and other studies where the pattern is constantly changing; 2. an analog recording dynamic analyzer (ARDA) for use with iodine-131 and other gamma-emitting isotopes in medical use; and 3. a general nuclear-laboratory counting system (pulse-height analyzer, linear rate meter, scaler, power supply).

. . . And 2 Others Discontinue Theirs

Nuclear Research Corp. has discontinued its six-month-old marketing agreement with RCA wherein RCA had been marketing a line of NRC-manufactured process-control gamma gages. RCA felt, it is understood, that there would not be enough gaging business available in the next few years to warrant continuation of the arrangement with Nuclear Research. NRC will market its own gages; however, RCA Service Co. will continue to service NRC gaging systems on customer's option.

DRD to Manage Radionuclide Power Generators

AEC's Division of Reactor Development (DRD) has won jurisdiction over the management of radionuclide power generators for all types of applications. The Division of Isotopes Development (DID) had sought management of this entire area of nuclear technology at AEC on the ground that it could give more attention to radionuclide power than DRD. However, AEC's new assistant general manager for research and development, Spofford English, resolved the dispute by assigning development of the generators to DRD and of the radioactive sources to DID. Heretofore, each division had sponsored its own generator and source development. Under the new arrangement, a requirement for a radionuclide power generator would be assigned for development to DRD; it, in turn, would advise DID that it had a requirement for a certain type of source.

Three Firms Report New Isotope Applications

Three firms reported interesting new uses for radionuclides last month:

1. **Resources Research, Inc.,** has developed a radionuclide method for detecting life on Mars under a $140,000 NASA contract. The Washington, D. C. firm has developed a detecting device, using carbon-14, which will be placed in the capsule of Mariner B, scheduled for a Mars fly-by in 1964. The study will be carried out by placing a carbon-14 compound, such as sugar, in a device with "tentacles" capable of digging into the surface of Mars. If bacteria are present, on or below the surface, they will take in the labelled compound, releasing a radioactive gas which will be measured on a Geiger-Mueller counter. The information will be radioed to the satellite, recorded on tape, and telemetered back to earth.

2. **Automation Industries, Inc.,** Torrance, Calif., has announced development of a new radionuclide technique for measuring fluid flow. The method is essentially a highly sensitive refinement of basic tracer techniques for accurate measurement of fluid volumes. Initially, Automation is using iodine-131 and gold-198; other isotopes might be considered, as required, for compatibility with various liquids. Much of the instrumentation is being manufactured by Automation and the rest is purchased and modified to increase reliability and sensitivity. Contracts were being negotiated with major oil companies; the company hopes to install its measuring equipment at such installations as chemical plants, oil refineries and pipelines, and electric-power stations. The firm has established a new division—Isotech—to exploit the technique.

3. **Giannini Controls Corp.,** under a $500,000 feasibility study subcontract from Bell Telephone Laboratories (prime contractor to the Army for the anti-missile missile, Nike-Zeus), is exploring a radionuclide back-scattering and absorption technique for measuring the distance, density, mach number and angle of attack of high velocity vehicles in outer space. Radionuclides aboard anti-missile missiles would send out a beam which would "bounce" from an enemy missile back to scintillation counters aboard the anti-missile missile. The Giannini device is one of several being considered by the Army for the Nike-Zeus program. The four-month-old feasibility study will be followed by a development contract—either with Giannini or another company after open bidding.

NUCLEONICS IN SPACE

Finger Takes on Electrical-Propulsion Management

Management of NASA's electrical-propulsion program was assigned on Nov. 1 to Harold B. Finger, who already had a big assignment in management of the U. S. nuclear-rocket program. At the same time NASA abolished an electrical-propulsion group at Marshall Space Flight Center (NU, Sept. '61, 27) and designated Lewis Research Center the prime development laboratory for these systems. Lewis immediately embarked on a personnel-recruitment program and announced it would begin construction next year of its second electrical-propulsion testing facility—this second one a $15–20-million tank-type facility near the Plum Brook reactor which will have capability for testing complete systems, including power reactors, in a simulated space environment. Lewis has had a research responsibility in electrical propulsion for some years but it is now charged with developing the complete systems and monitoring NASA contracts in this field with industry.

Finger now has the following management roles: 1. director of the AEC-NASA Space Nuclear Propulsion Office (nuclear rocket); and 2. NASA director of nuclear systems, which encompasses NASA's electrical-propulsion program—including SNAP-8, the first of these systems to use nuclear power—and the agency's interest in nuclear power for other space applications (communication satellites, etc.). While Finger has management responsibility for the entire nuclear-rocket effort (reactor, engine and vehicle), he has no nuclear responsibility for either electrical propulsion or power supplies. AEC will continue to develop nuclear-power sources in both areas. There is a further division of responsibility in the electrical-propulsion area; that is, the Air Force has a program of its own to develop systems of the same size and has asked AEC to develop appropriate power reactors (NU, Nov. '61, 48).

NASA Program. The assignment of electrical propulsion to Finger constitutes an upgrading of this program within NASA; the agency has heretofore resisted a sizeable investment in this technology, most recently cutting its $5–6-million budget for advanced research-development in half. However, NASA officials expect a substantial increase in all phases of electrical propulsion during fiscal-year 1963, which begins next July 1. Aside from the 60-kwe SNAP-8, which was programmed through 1965 some time ago, the major effort has been and will continue to be development of engine systems of 1-Mwe and higher; AEC must develop the reactors for these systems but NASA has chief responsibility for the conversion and electrical-propulsion phases. It would like to be in a position to flight-test the first megawatt system in the late 1960's, at an estimated cost of $200-million. In the meantime, it is supporting a major research-development program at Lewis and a series of contracts with industry on basic materials. Some of these contracts:

Pratt & Whitney. Improvement of heat-radiator capability by trying to develop coatings that would increase emissivity. Radiator size-and-efficiency is considered a major technical problem for large systems.

M-B Associates, Walnut Creek, Calif. Initial design of a hypervelocity gun to simulate meteroids for radiator damage studies, etc.

Battelle Memorial Institute. Studies of potassium properties in the 900–1,200°F. range.

General Electric. Two contracts: 1. design and fabrication (by May 1962) of a 2-stage potassium turbine to operate at 1,600°F; and 2. development of liquid-metal bearings for high-temperature operation.

General Atomic. Development of thermionic-cathode materials (for example, zirconium and uranium carbide) for operation at 2,300–2,400° kelvin.

Spence Succeeding Schreiber on Nuclear Rocket

Roderick W. Spence will succeed Raemer E. Schreiber as nuclear-rocket chief at Los Alamos Scientific Laboratory (LASL) on Jan. 1. Schreiber has been promoted to succeed Darol K. Froman as technical associate director of LASL under Norris E. Bradbury; Froman will retire at year's end. Spence has been alternate leader of N Division, under Schreiber, since 1955. The division's principal development project has been the graphite reactor for nuclear rocketry. In an interview at the International Symposium on Aerospace Nuclear Propulsion—in Las Vegas in late October—Schreiber discussed some of the things N Division might be doing after development of the Kiwi reactor. Within a year, he said, LASL hopes to turn over to the engine developers, Aerojet General Corp. and Westinghouse Astronuclear Lab, a reactor which "will do the job" in the first nuclear-rocket engines. The lab will then go on to more advanced systems, probably concentrating on increasing the power density of Kiwi-type, solid-core reactors (Project Phoebus). He did not rule out the possibility of going also to more advanced systems but said "this is longer range." He also pointed out that one of the results of a successful Kiwi program during the next few months "hopefully will be support for going in the direction" of nuclear-rocket-booster development.

Seaborg Pledges Space-Reactor Development

AEC Chairman Glenn T. Seaborg pledged AEC in late October to develop large, high-temperature reactor systems for auxiliary and electrical-propulsion power in outer space. He delivered the banquet address at the International Aerospace meeting in Las Vegas (see previous story). Seaborg recognized officially what some in government and industry have been warning of for some time—that the U. S. was developing large rocket boosters and consequent payload requirements faster than the power supplies. "It is therefore," Seaborg said, "that we concentrate even greater resources with an even greater sense of urgency on development of compact nuclear reactors." He noted that the largest SNAP reactor, SNAP-8, would not be operational before late 1965 and only as a 60-kwe system. "Larger power sources, from several hundred kilowatts into the megawatt range, will be available some years after 1965. On the other hand, booster rockets, payloads and missions will be available earlier." With this situation unfolding, he said, AEC will embark on development of liquid-metal, fast reactor systems capable of delivering a megawatt or more of power and, at the appropriate time, fast, thermionic systems of comparable power and lighter weight."

During a press conference preceding his speech, Seaborg revealed that AEC and NASA were seeking an increase of about 50% in the nuclear-rocket budget for fiscal 1963; this year's budget is $90-million. Seaborg said a substantial portion of the proposed increase would be spent by NASA, reflecting the growth of its engine and vehicle programs.

Seaborg also insisted, in answering a question, that the expanding nuclear-weapons-test program would not be permitted to take people from the rocket program.

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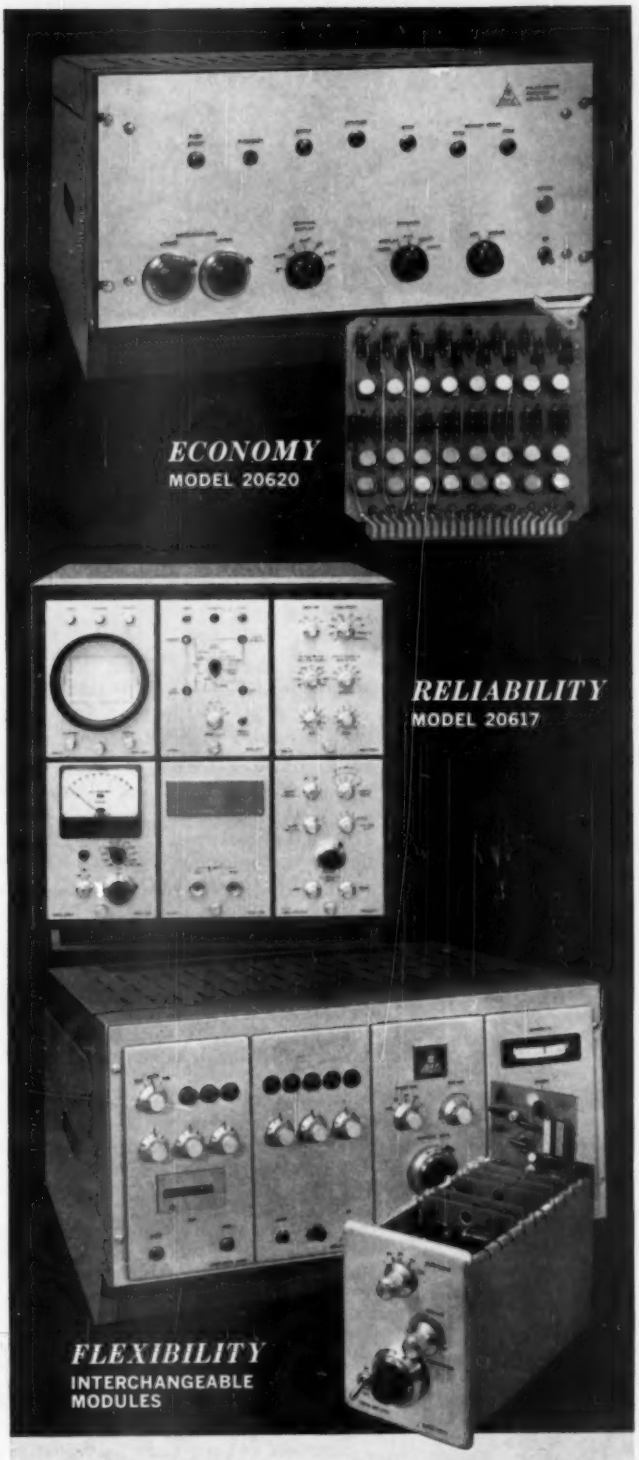

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GENERAL ATOMIC ANNOUNCES

Opportunities for Scientists and Engineers

Harnessing nuclear power for propulsion of large space vehicles is one of the many advanced programs underway at General Atomic's John Jay Hopkins Laboratory in San Diego, California. This and other programs directed toward the creation of more efficient and economical power production and conversion systems have resulted in career opportunities for scientists and engineers in the following areas:

- EXPERIMENTAL PHYSICISTS—for solid state and semiconductor studies, acoustics, high vacuum systems, plasma devices, shock tube and high energy particle physics, photonuclear research, radiation effects, nuclear physics, high altitude studies.
- THEORETICAL PHYSICISTS—for solid state and atomic physics, plasma theory, and hydrodynamics.
- REACTOR PHYSICISTS—for reactor analysis and design, hazards analysis, and thermionic reactors.
- CHEMISTS—for radiochemistry, fuel cell research, physical and nuclear chemistry, and activation analysis.
- METALLURGISTS—for analysis of structural materials for reactor systems, fuel cells, thermoelectric and super-conducting materials, high temperature corrosion and high vacuum work.
- MATHEMATICIANS—for scientific programming, numerical analysis, and systems analysis.
- PROJECT ENGINEERS—for engineering aspects of reactor design and development, electrical power and distribution systems, structural analysis, field liaison on heavy construction (both civil and electrical), and space vehicle and power plant design.
- ELECTRONICS—for development of new devices, nuclear instrumentation, dynamic analysis and control systems, and thermoelectric devices.

Located in northern San Diego, the John Jay Hopkins Laboratory is the largest and most diversified privately owned nuclear laboratory in the world. In addition to nuclear space vehicle propulsion, other advanced programs include: high temperature gas-cooled reactors for electric power generation... beryllium oxide-moderated gas-cooled reactors for ship propulsion and other power applications... systems for the direct conversion of heat to electricity... controlled thermonuclear research... TRIGA reactors for training, research, isotope production, and medical and industrial uses... and basic research in the sciences.

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GENERAL DYNAMICS | GENERAL ATOMIC DIVISION

NUCLEONICS MARKETS

Q. WHAT percentage of central station power plants sold in 1970 will be nuclear?

Q. WHEN will 25 compact military reactors be critical? 1965? 1967? 1970?

Q. HOW MUCH will the AEC and NASA spend for nuclear-space programs in 1965?

A. Look in the new NUCLEONICS marketing report that answers these and many other questions about the nuclear market. The following markets are analyzed:

- Nuclear Navy
- Compact Military Power Reactors
- Nuclear-Energy-In-Space
- Central Station Power Reactors
- Major Components

This market study is published in the latest issue of NUCLEONICS Markets. If you are an executive, or a marketing or sales person and would like to receive this study and subsequent copies of NUCLEONICS Markets, write today to:

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Roumania	2
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Switzerland	91
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ASIA	833
Burma	3
Java	10
Ceylon	2
Formosa	25
Hong Kong	6
India	84
Iran	7
Iraq	3
Israel	34
Japan	572
Korea	13
Lebanon	4
Malaya	3
New Guinea	1
Pakistan	9
Philippines	25
Saudi Arabia	1
Singapore	2
Sumatra	1
Syria	1
Thailand (Siam)	10
Turkey	16
Other Asia	1
AFRICA	64
Algeria	5
British East Africa	2
British West Africa	1
Congo Republic	5
Egypt	9
Ethiopia	1
Ghana	1
Morocco	1
Nigeria	1
Rhodesia (Northern)	1
Rhodesia (Southern)	4
Tunisia	1
Union of So. Africa	31
Other Africa	1
AUSTRALASIA	106
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TOTAL U.S. POSSESSIONS	27
TOTAL	4,184

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Please contact: Mr. C. M. Newton,
Personnel Office, Atomics International,
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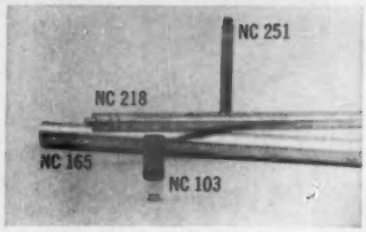

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Outstanding developments in more glamorous areas of radioactivity measurement have overshadowed the workhorse of the isotope laboratory, the nuclear scaler. Rarely is a new scaler promoted in advertisements. And yet — the versatility of most counting systems is directly related to the design features of the scaling instrument.

Of the dozens of scalers available, Nuclear-Chicago's new 202 Decade Scaler pictured above is the finest complete scaler. It is a fully automatic instrument for use with all G-M, scintillation, or proportional detectors. Note these features: (1) a non-overloading linear amplifier with input sensitivity from 1 mv to 2 v controlled by fixed precision attenuators, (2) a resolution time of 1 microsecond, (3) six decades, (4) electronic timing to 100 minutes in increments of 0.01 minute, (5) both preset count and preset time control, (6) pushbutton electronic start, stop, and reset, (7) regulated low voltage power supply, and (8) regulated high voltage supply variable from 500 to 5000 volts in two ranges with a precision ten-turn control.

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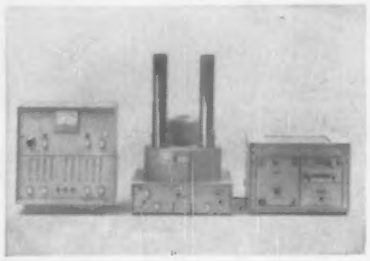

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An automatic sample changer is an investment which usually pays for itself in a short period of time. Day after day, it programs samples and collects digital or analog data for later use. However, an automatic sample changer is a poor investment if it is not combined with a readout system capable of providing all the needed data.

The 202 Decade Scaler (described above) and new 8400 Digital Recorder are an ideal combination for data readout. The digital recorder simultaneously prints sample index numbers with both time and count information. Once commanded to print by the scaler, the 8400 Recorder supplies reset and start commands to the automatic sample changer connected to it.

Thirteen predetermined time or thirteen predetermined count settings can be selected at the 202 Scaler. A time/count control is provided to command the 8400 Recorder to print when either the preset time or preset count is reached so that samples with low counting rates will not unnecessarily delay the counting cycle.

All Nuclear-Chicago automatic sample changers can be programmed with the 8400 Digital Recorder and 202 Decade Scaler. Detailed specifications on these instruments and on the complete Nuclear-Chicago line are contained in General Catalog S, available on request.

nuclear-chicago
CORPORATION

345 East Howard Avenue, Des Plaines, Illinois

NUCLEONICS REACTOR FILE . . . No. 10

Reactors on the Line

BERKELEY

Berkeley Nuclear Power Station

Characteristics of BERKELEY

Location • Berkeley, Gloucestershire, England
Owner & Operator • U. K. Central Electricity Generating Board
Reactor-system design • The Nuclear Power Group
Construction; plant design • The Nuclear Power Group
Output (Mw)—thermal • 565/reactor; 1,130 total
—net electrical • 138/reactor; 275 total

Reactor Design Data
(for each of two reactors)

Pressure vessel

		Material:	0.1–0.25% Si-killed mild steel
Outside height, i.d.:	80 ft; 50 ft	—inside cladding:	None (gas cools hottest parts)
Wall thickness:	3 in.	Design pressure:	125 psig

Core

Size: 24 ft x 44 ft dia polygonal cylinder
Weight: 253 tonnes U, 2,000 tonnes graphite

Fuel elements

Type:	U rods in Mg tubes	Element, length:	24 in.
Enrichment:	0.7% (natl.)	weight:	17 lb
Number:	3,275 vertical fuel-element channels; 13 elements per channel, one atop another; total 42,575 elements	U rod size:	1.1 in. dia x 19 in.
		Cladding:	Magnox-A12 cans with fins
		Burnup, avg:	3,000 Mwd/tonne
		U max. temp:	1,022°F
Rods/element:	One	Clad max. temp:	896°F

Control rods

No., size, shape:	132 1.75-in.-diameter rods	Rod cladding:	0.1-in. stainless steel
		Withdrawal rate:	0.433 in./min
Absorber, length:	25.5 ft		
material:	4.25w/o boron in steel	Scram time:	6 sec for 80% insertion

Nuclear Design Data

Thermal-neutron flux (avg): 9.6×10^{13} n/cm²/sec
Thermal-neutron life: 10^{-3} sec
Control capability—total rod worth: 4.5%Δk/k (cold, clean)

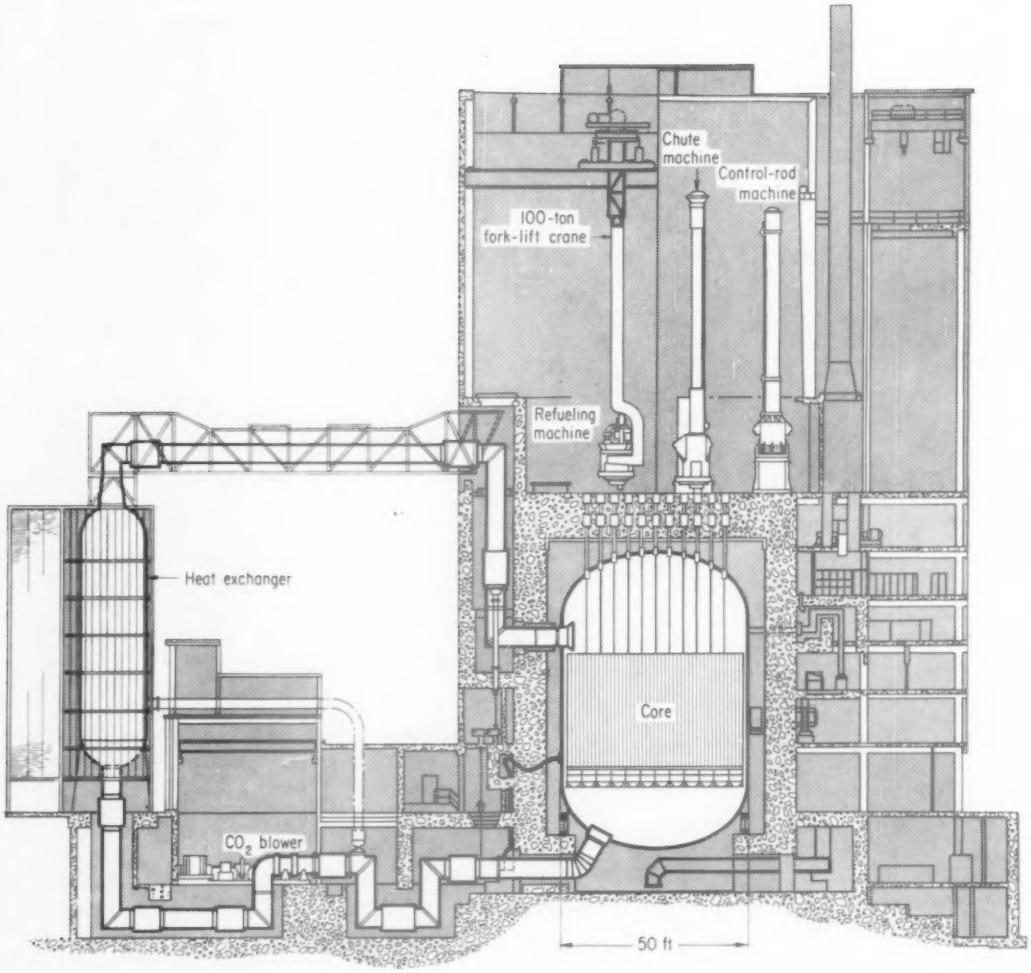
Heat Transfer Data

Coolant:	CO_2	Operating pressure:	139 psia
Flow:	6.6 ft/sec (max); 6,358 lb/sec	Pressure drop:	4 psi (core)
		Steam:	604°F at 310 and 72 psia
Temp.—inlet:	320°F		
—outlet:	653°F	Turbine:	2/reactor

Loops: 8/reactor; 1 axial-flow circulator/loop; each a-c circulator requires 3,800 hp to boost pressure of 805 lb/sec of 311°F 132.5-psia CO_2 by 7.25 psi while turning at 3,725–2,903 rpm

REACTOR FILE . . . NO. 10

BERKE



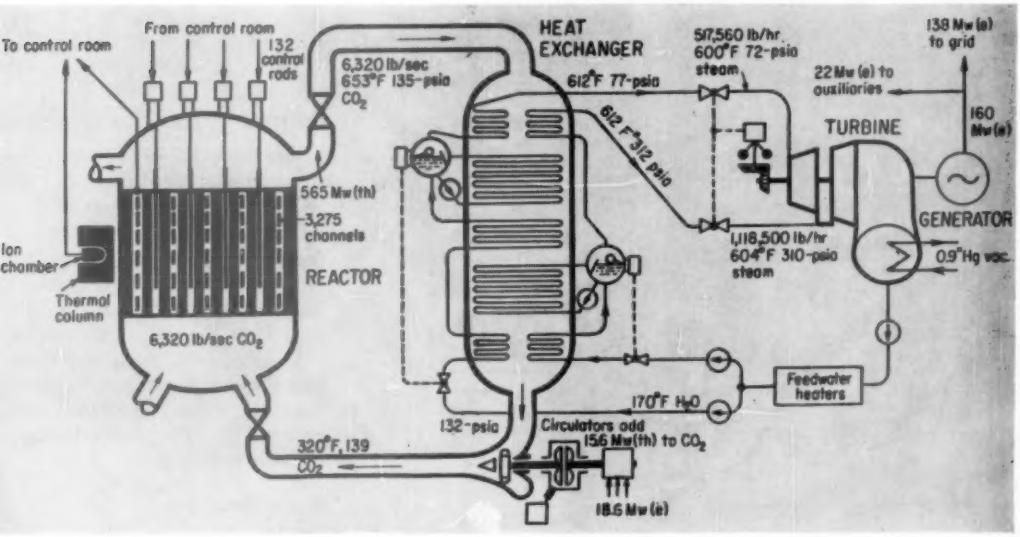
1 **REACTOR VESSELS** at Berkeley, like those at Calder Hall and Chapelcross, are cylindrical (larger later reactors are in spherical vessels). With a cylinder it is easier to load fuel and vary fuel-channel length. For the same 3-in. vessel thickness, a 67-ft sphere would have permitted 10% greater pressure than the 50-ft-diameter cylinder, but the extra cost of fabricating a big sphere and a larger shield would balance out the benefit of extra power. After the 200-ton lower dome was welded together nearby and moved to its foundations (16 short "rolling" columns with rounded bearing surfaces that permit radial expansion when vessel temperature changes), steel lining for concrete biological shield was built (so vessel welding could proceed inside under shop conditions) and concrete shield was poured. Rather than massive 200–400-ton straddle cranes used to lift large vessel sections in place for all other UK reactors, for economy Berkeley builders used 15-ton monotower cranes, small plate sections

ELEY on the Line

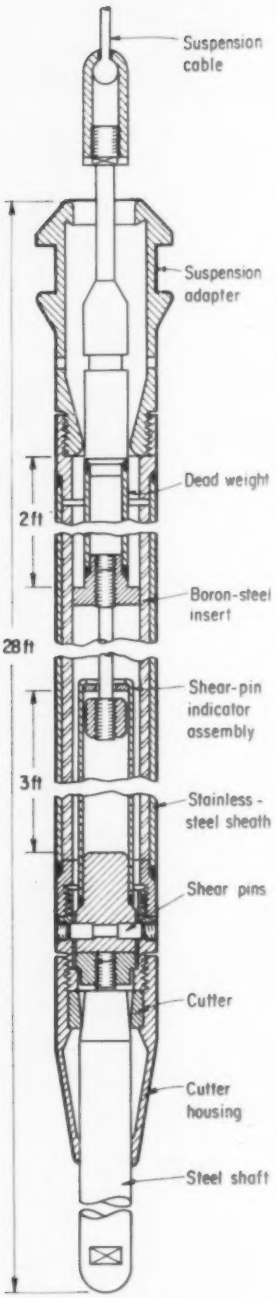
Fifteen months after ground was broken Jan. 7, 1957, he first boiler was lifted into position. By the end of March, 1959, the first reactor vessel had been stress-relieved and by June it was tested at 1½ times design pressure. April, 1961, saw the beginning of systems checks, which included trials of warm steam and gas circuits and tests of refueling equipment. Fuel loading began August 12 and Berkeley No. 1 went critical August 27 with 744 channels loaded (52.1 tonnes U) of 3,275 channels (232 tonnes) available. This first Berkeley reactor is expected to reach full power early in 1962. The second reactor will follow about six months later.

In December, 1956, the UK Central Electricity Generating Board awarded the Berkeley design and construction contract to the consortium of Associated Electrical Industries, Ltd., and John Thompson Nuclear Energy Co. (which merged four years later with the Nuclear Power Plant Co., designer-builder of the Bradwell station, to form the Nuclear Power Group). This was only two months after the first of the plutonium-producing Calder Hall reactors went into commercial operation, but since then many modifications dictated by Calder and Windscale experience have been included in the Berkeley reactors. For instance, the decision to rebore the lower one-third of the coolant channels and add magnox sleeves was made in November 1958, after a progressive release of stored Wigner energy in an uninstrumented region caused a fire in the graphite of one of the air-cooled Windscale reactors. (Although since then the Wigner prediction for Berkeley has proved unduly pessimistic, the sleeves have been retained for cost and schedule reasons; but 243 thermocouples in the graphite permit continuing checks.)

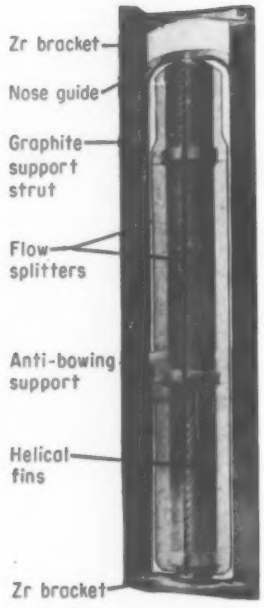
Other modifications since construction started include local thickening of biological shield, more thorough inspection of pressure vessel plates and welds, additional instrumentation (such as more thermocouples and temperature-data loggers with magnetic drum storage and printed output), sector temperature control by the control rods, and moderator pins to restrain graphite shrinkage. New control-rod scramming devices actuated by gas pressure will be installed early in 1962. Cumulatively, these changes delayed operation by a year and raised costs.



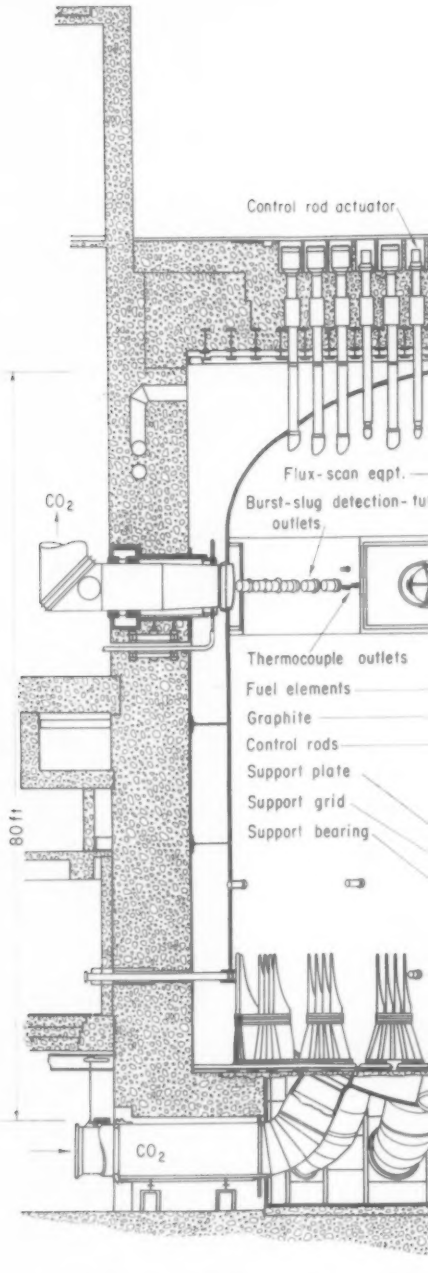
2 EACH REACTOR has eight coolant loops radially arranged around the reactor in two sets of four (flow quantities shown here are for one reactor). Each loop has a crossflow boiler (70 ft high, 17.5 ft diameter, 1⅛ in. wall), a 3,800-bhp blower with variable-speed fluid couplings (plus a pony motor and a flywheel), 5-ft-diameter ducts of ⅜-in. mild-steel plate, two pneumatically operated 5-ft isolation valves, driers and 2%-bypass filters. Blower shaft seals are of oil-wetted type; canned pumps circulate water in steam circuit. Two 85-Mw(e) turbogenerators serve each reactor system. The boilers, each of which combines economizer, evaporator and superheater tubes in one shell, basically are similar to those at Calder Hall, but (except for the superheater banks) all steam tubes have integral-rolled fins and the tubes are packed more tightly. As with all the British reactors, boilers are higher than reactor so natural convection can remove 10% of full-power reactor heat if the carbon-dioxide blowers fail



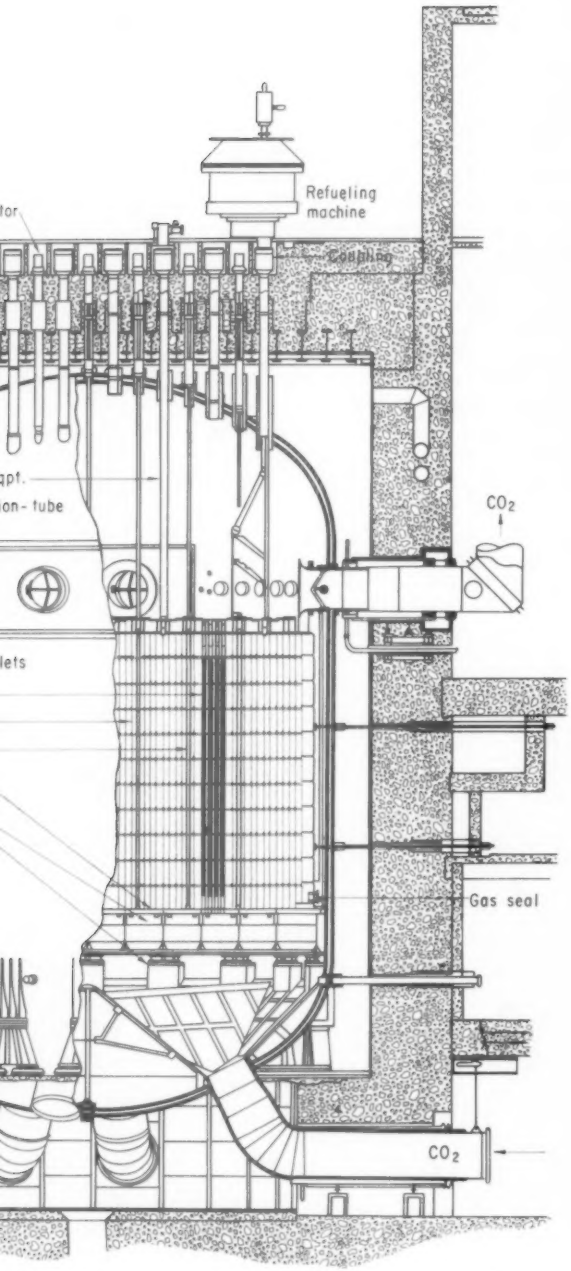
3 A CONTROL ROD consists of a 4.25w/o-boron-in-steel cast tube inside a stainless-steel cladding tube. To absorb force of 80-ft accidental fall from charge face into reactor, impact would drive the protruding shaft into the rod center through the annular cutter



4 EACH FUEL ELEMENT consists of natural-uranium slug canned in helically finned magnox tube. Graphite struts support can between zirconium top and bottom brackets; to flatten flux radially, stainless-steel brackets replace zirconium brackets in central-region fuel elements



5 GRID THAT SUPPORTS graphite moderc structure rests on 16 roller-bearing assemb directly above 16 vessel main support columns; f center graphite stacks in core fasten to supp plates so they stay at vessel axis; all other sta rest on ball bearings on support plates, which h radial keys to allow differential expansion; cr braced ring girders carry entire core assem Flexible seals between lower part of graphite st



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ture and vessel wall prevent any CO_2 from bypassing core, but to keep vessel wall below creep range ~110 lb/sec CO_2 diverts (above seal) into annulus between vessel and steel liner that extends to center of top dome, from which point CO_2 exits with bulk coolant gas; 80 thermocouples measure vessel temperature so operators can adjust flow suitably during initial startup. Nozzles at bottom of low-flux coolant channels flatten temperature profile

Descrip

Like all the British nuclear power
Berkeley has two reactors cooled by carbo
moderated by graphite and fueled wit
uranium. Both the two Berkeley 554-M
the two Bradwell 531-Mw(th) reactors
giant intermediate steps from the eight 20
Calder Hall and Chapelcross reactors to
800–1,000-Mw(th) reactors being built a
Point, Trawsfynydd, Dungeness and S

Viewed in perspective, the Berkeley a
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- went from 2-in.-thick plate—consid
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Calder was being built—to 3-in. plate so
pressure could be boosted 25%
- raised fuel cladding temperature a cri
(to 806°F)
- and boosted steam pressure 66% (to 3
606°F).

With this system and 149 psia carbo
pressure Berkeley achieves a 24.75% th
ciency against Calder's 18%. Berkeley
machines for refueling while the reactor is

Reactor Vessel and Shielding

Operation as hot as 650°F and prev
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In June, 1957, after most of the concr
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principally in the reactor building (to 8
the blower houses.

Core Structure

Fuel elements are stacked vertically 1
4-in.-diameter coolant channels bored
vertical axes of the graphite moderator b
channels are on an 8-in. square pitc
$13\frac{1}{16}$-in.-wide $\frac{3}{4}$-in.-deep keyways cut
channels receive the fuel-element suppo
To accommodate control rods, neutron
and sources, $3\frac{1}{4}$-in.-diameter vertical ch
formed by quadrant fillets machined from
rounding bricks.

The moderator-reflector lattice consists
97,000 pieces of graphite of 400 differe
(machined from extruded blocks 8.55 in.

Description of BERKELEY

Like all the British nuclear power stations, Berkeley has two reactors cooled by carbon dioxide, moderated by graphite and fueled with natural uranium. Both the two Berkeley 554-Mw(th) and the two Bradwell 531-Mw(th) reactors represent somewhat intermediate steps from the eight 200-Mw(th) Calder Hall and Chapelcross reactors to the eight 500-1,000-Mw(th) reactors being built at Hinkley Point, Trawsfynydd, Dungeness and Sizewell.

Viewed in perspective, the Berkeley and Bradwell advances over Calder now appear modest compared with the sophistication that is following in later designs as this uniquely British reactor type evolves. But the technology jump is real enough. Although Berkeley is the smallest and the most conservative of all designs after Calder (it was the only station to stay with cylindrical reactor vessels),

- went from 2-in.-thick plate—considered the maximum for on-site vessel fabrication when Calder was being built—to 3-in. plate so that CO_2 pressure could be boosted 25%
- raised fuel cladding temperature a critical 40°F (806°F)
- and boosted steam pressure 66% (to 325 psia at 750°F).

With this system and 149 psia carbon dioxide pressure Berkeley achieves a 24.75% thermal efficiency against Calder's 18%. Berkeley also has machines for refueling while the reactor is operating.

Reactor Vessel and Shielding

Operation as hot as 650°F and prevention of brittle fracture during or after field fabrication involve conflicting requirements. But a silicon-killed mild steel (1.5% Mn, 0.1–0.25% Si and maximums of 0.16% C, 0.05% S, 0.05% P) has safe operating properties and a ductile-brittle transition temperature that is low enough for on-site welding; its ultimate tensile strength is 56,000–64,000 psi.

In June, 1957, after most of the concrete shield had been built, tightened radiological standards made it necessary to thicken the concrete shield—principally in the reactor building (to 8 ft) and in the blower houses.

Core Structure

Fuel elements are stacked vertically 13 high in 4-in.-diameter coolant channels bored along the vertical axes of the graphite moderator bricks (the channels are on an 8-in. square pitch). Two 1-in.-wide ¾-in.-deep keyways cut down the channels receive the fuel-element support struts. To accommodate control rods, neutron detectors and sources, 3¼-in.-diameter vertical channels are formed by quadrant fillets machined from four surrounding bricks.

The moderator-reflector lattice consists of about 4,000 pieces of graphite of 400 different shapes machined from extruded blocks 8.55 in. square by 32 in. high). The graphite bricks are stacked in 11 layers with horizontal layers of graphite tiles between brick layers. To prevent neutron streaming through gaps in the stack, the moderator bricks are rotated 2 deg with respect to the tiles. At each tile layer and at the top and bottom reflector layers tubular tie-bars link together around the periphery of the graphite stack to hold it together radially; so the linkage will have the same thermal expansion as the graphite, some tie-bars are mild steel and others are stainless steel.

Calder and Harwell data showed that graphite shrinks at the higher temperatures expected at Berkeley. Thus in July, 1959, it was decided to remachine the Berkeley bricks extensively and to pin the tiles in the higher flux regions with zirconium rods to prevent distortion and gas leakage between bricks when the graphite shrinks.

Control Rods and Drives

A pressurized motor above the shield raises and lowers each control rod. The motor, mounted on a standpipe flange, turns a winding drum containing the steel hoisting cable by means of a shaft that passes through the upper shield. Of the 132 control rods in each reactor, 20 are safety rods (1% $\Delta k/k$ in group), two other groups (56 rods in each) serve as regulating rods. To dampen radial flux instabilities due to burnup and xenon buildup and to hold average channel gas outlet temperature constant regardless of power level, in March, 1958, it was decided to have separate control loops regulate control-rod positions independently in a central and eight radial sectors of the core. Each zone has an automatic controller that receives signals from one of two groups of thermocouples (312 on fuel channels in each reactor) in the zone and transmits impulses to the zone regulating rod. The thermocouple groups produce two average-channel outlet gas temperatures that are referenced and then the highest passes to a control unit in which integral and derivative terms are incorporated to modify the loop transfer function. Variations in controller output are converted to pulses that power regulating-rod actuators.

To change plant and reactor power output the operator at the central control panel changes blower speed so as to vary the amount of carbon dioxide circulating through the system. Then the control rods automatically move to hold carbon dioxide inlet and exit temperatures constant, and steam pressure changes to keep turbine speed constant.

Load can be changed 4%/min without causing harmful thermal shock to any component.

During 1962 new backup scram circuits will be installed to shut the reactors down if coolant pressure changes rapidly (CEGB authorized these circuits in December, 1960). The rod-drop initiators at the top of each control rod will consist of a sensitive bellows into which carbon dioxide from the reactor can pass through a restrictor orifice. Quick pressure rise will expand the bellows, releasing the claw that supports the control rod.

Fuel Elements

To stay below uranium alpha-beta phase change at 1,220°F and to allow margin for hot-channel factors and normal reactor transients, the fuel elements are designed so that their centers will not exceed 1,022°F. Although tests show that the fuel-element materials can satisfactorily withstand a cladding temperature of 896°F or more (from standpoints of oxidation, creep, grain growth of the magnox cladding and the swelling and phase changes of uranium), 806°F was used for design.

From an economic standpoint fuel burnup must be at least 2,500 Mwd/tonne, which is considerably greater than achieved in the plutonium-producing Calder Hall and Chapelcross reactors. When the Berkeley fuel elements were first designed the uranium was expected to lengthen only 5% during operation. But radiation-damage tests by November, 1957, showed that more swelling could be expected, so the graphite struts and top cap and guide were redesigned to accommodate 20% swelling (nose guide is free to rise by sliding in slots in graphite struts; magnox support that also fits into slots prevents cartridge bowing).

Because most pinhole failures of the Calder Hall fuel elements occurred in the cap weld, improved welding methods were developed for Berkeley.

To check cladding temperatures during reactor operation, 354 thermocouples attached to selected fuel elements connect through spring-loaded contacts on the frame to permanent compensating leads in the graphite moderator.

Refueling

Berkeley and Bradwell reactors will be the first in the UK whose fuel can be loaded and unloaded while the reactor is operating at full power and pressure. Plans are to reload ten channels per week (13 fuel elements per channel) by 1963. Fuel elements are loaded and unloaded through 54 standpipes (on a 32-in.-square lattice) that extend from the top of the 11-ft-thick biological shield down through the reactor vessel to the top of the graphite core 40 ft below. Each standpipe and its gas flapper valve serve 64 fuel channels.

With one chute and two refueling machines for each reactor up to eight channels can be refueled in each reactor per day. Although plans were to increase average burnup by axially shuffling the 13 fuel elements in every channel, the chance of damaging the elements by this extra handling has discouraged this plan.

REPRINTS of this and earlier foldouts and the entire collection on a Microcard are available—Readers' Service Dept., NUCLEONICS

What Have We Learned? . . .

Health Physics at SL-1

From first-hand experience at SL-1 we can evaluate our ability to deal with nuclear accidents. For the future we must have larger-range detectors and better methods for handling radioactive casualties

by JOHN R. HORAN and C. WAYNE BILLS
Health and Safety Division, AEC Idaho Operations Office, Idaho Falls, Idaho

AT THE SL-1 ACCIDENT earlier this year, health physicists encountered many "firsts" in health-physics operations and management. Moreover they were able to evaluate how well their preplanned program worked in a nuclear disaster area and what improvements they must make. The experience of the rescue crews working in a highly contaminated environment point out the following important facts about existing health-physics techniques.

• Preplanned program worked well. Although there is, of course, room for improvement in existing health-physics techniques, the preplanned operation allowed rescue crews not only to enter the reactor room where radiation levels were 500–1,000 r/hr, but also to remove the bodies of the three men killed in the accident without further injuries or casualties. Moreover the radiation exposures that members of the early rescue crews received will not keep these men from working in any nuclear programs in the future.

• But we must improve. In particular the SL-1 disaster points up a void in the preplanned technique for dealing with highly radioactive casualties. In addition the rescue crew that originally arrived on the scene was not equipped with instruments that recorded radiation levels above 500 r/hr. Consequently the crew could not determine the extent of the radiation in the reactor room (see box on Page 44 for improvements).

• We learned from experience. From the SL-1 disaster we not only gained valuable practical health-physics experience, but also were able to analyze our preparedness and ability to handle nuclear accidents in the future. Moreover we gained confidence in dealing with nuclear emergencies.

Preplanning Pays Off

In responding to the SL-1 fire alarm—potentially involving radiation hazards—the division followed its preplanned emergency health-physics program as its fire trucks rolled toward the Army Reactors Experimental Area on that first Tuesday evening in January. This program, set up by the AEC Health and Safety Division at Idaho Falls, (see Box on page 46) not only provides equipment to deal with accidents but also outlines the basic procedures and responsibilities needed to cope with all kinds of emergency situations—plant incidents, natural disasters, enemy attack or security alerts.

An important part of the program is a general notification system that the Health and Safety Division uses not only to request on-site, off-site or off-duty health-physics assistance, but

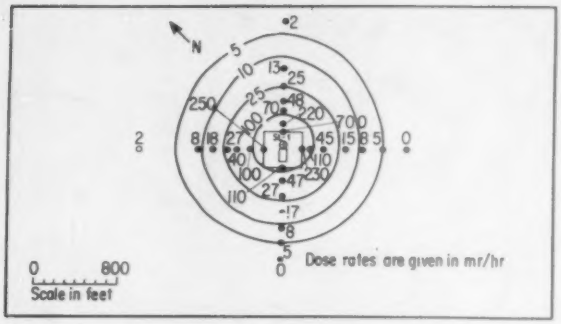

FIG. 1. CONTAMINATION TO ENVIRONMENT was small since major radiation was confined to reactor building

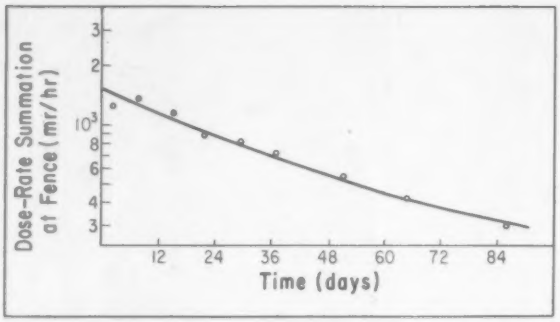

FIG. 2. SUMMATION OF DOSE RATES AT FENCE shows half life of ~36 days indicating long-lived fission products

also to notify downwind facilities of an accident after determining meteorological conditions. The IDO fire department used this system when at 9:02 p.m. on Jan. 3 they requested health-physics assistance from Phillips Petroleum Company at MTR. The program also sets up a field headquarters complete with decontamination and counting-trailer facilities; this field station reports directly to a headquarters control group. In addition, through discussions of plans for action, reviews of possible incidents and field responses to simulated accidents, the radiological assistance plan develops the response capability of the AEC and its contractors. This program provides 30 people trained in health physics and medical practices to deal with emergencies at NRTS. Preplanning also set up exposure guides for workers in a disaster area: they allowed a 100-roentgen dose to a man trying to save a life and a 25-roentgen dose for a man protecting valuable property (Table 1).

The importance of this preplanning became evident when the fire department answered the alarm from the reactor. For example, although the SL-1 site was kept locked instead of having a 24-hr guard, the IDO security and fire department could quickly enter

What We Learned and How We Are Improving Health-Physics Techniques

The most valuable health-physics information from the SL-1 accident comes from analyses of our ability and preparedness to handle nuclear accidents in the future. Although we had reviewed many hazard reports and had discussed the worst possible accidents at NRTS, we found at SL-1 that our actual health-physics preparations were inadequate in several areas. In the table below we have listed some of these inadequacies as well as the improvements we are making.

What we should do . . .	Therefore . . .
• Improve our ability to handle radioactive casualties so that personnel will not be exposed to large doses.	• We should have available concrete vaults for transporting contaminated bodies. Also we are evaluating remote decontamination and surgical equipment for handling casualties.
• Maintain more emergency equipment—easily available—on a standby basis; in particular, we should increase the range of detectors and keep a larger supply of full-face masks.	• We are increasing amount of emergency equipment and are supplementing 500-r/hr-range gamma detectors up to 5,000-r/hr-range detectors.
• Have more trained health-physics personnel at disaster site earlier.	• We have taken responsibility for establishing field headquarters away from health-physics group so they will be freer to go directly to disaster site.
• Increase fire department training in health-physics practices.	• Our fire department personnel are receiving more health-physics training.
• Evaluate whether fire department officers should wear alarm dosimeters.	• We are testing and evaluating alarm badges.
• Establish better control at roadblock.	• By having better control we can reduce exposures, insure film-badge coverage of all personnel and prevent spread of contamination.

FIG. 3. HEALTH PHYSICISTS MEASURING GAMMA COUNT from sagebrush found no appreciable contamination

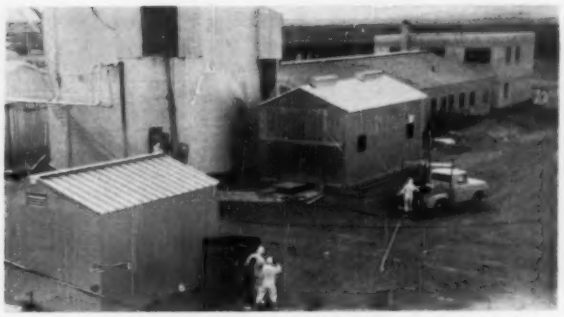

FIG. 4. TO KEEP EXPOSURE TO MINIMUM when removing bodies crew near reactor used protective clothing and shields

the reactor area at the gate house because preplanning had provided them with a key to the enclosure. The men were also equipped and trained to make radiological survey checks when they entered areas without qualified health-physics coverage even though in this case they did not realize that a reactor accident had taken place. Preplanning had provided all roving security patrols with direct survey instruments and the fire department with 500-r/hr-range Jordan Radectors.

When the men reaching the stairs to the reactor room found dose rates of ~10 r/hr they had the first evidence that a major accident had taken place inside the reactor compartment. Since pretraining had emphasized that exposures must be kept to a minimum and qualified health-physics assistance must be secured when radiation is high, the firemen waited outside the building until health physicists arrived from MTR and they could plan their next moves.

Disaster plans at Idaho Falls. While the group made its plans, the evidence of large radiation levels had set a vast organizational plan into action 40 miles away at the AEC headquarters in Idaho Falls. Key people were notified, and the NRTS emergency and disaster plan went into action. At 10:25 p.m. the director of Health and Safety called a Class I disaster; this is an emergency in a single area that involves much property and personnel but can be controlled by people in the area with standby assistance from the NRTS fire department, medical and health-and-safety personnel. As it is defined, a Class I disaster actually applies to a larger facility than SL-1 at which the contractor keeps more men even during off-shifts who can help control an accident. Therefore at SL-1 additional contractor personnel including Army cadre men—recruits in training at SL-1 under the supervision of the contractor—had to be called in to assist at the emergency operations.

What were hazards? With the death of the only survivor of the accident at 11:14 p.m. the early emergency phase of operations ended and the crews could pause, take stock of the situation and make plans for recovering the remaining two bodies in the reactor room. They started with two clear-cut problems at hand: first, decontamination of early entry teams and evaluation of their doses; second, evaluation of environment contamination and establishment of the control area around SL-1. In this phase health-physics workers from all NRTS contractors began to arrive at SL-1 and were given assignments.

One administrative problem arose as a result of our using help from these outside groups; many of the organizations had different exposure criteria and, therefore, the range of total permissible exposures for each individual as outlined by the respective managements ranged from 60 mr/day to 25

TABLE 1—Exposure Guides in Early SL-1 Recovery Efforts

Date	*Guide*
Jan. 3	<100 r for life-saving missions >100 r at discretion of senior health physicist <25 r to prevent major property loss
Jan. 4	<12½ r to recover second body
Jan. 5	Up to 10 men to receive <10 r in recovering third body and decontaminating bodies
Jan. 6	<3 r for all other operations

NUCLEONICS and NUCLEONICS WEEK Cover SL-1

Five feature articles cover the events of the accident; one is based on on-the-spot coverage by a NUCLEONICS editor.

Explosion at SL-1 Kills Three, First Reactor Fatalities, NU Wk, Jan. 5, 1
SL-1 Inquiry Proceeds Slowly; Cause of Accident Still a Mystery, NU Wk, Jan. 12, 1
SL-1 Explosion Kills 3; Cause and Significance Still Unclear, NU, Feb., 17
AEC's Pittman Reports on the SL-1 Accident, NU March, 62
SL-1 Radiation Down Sharply After Cleanup; Remove Vessel? NU, Oct., 22
For background: ALPR on the Line, Reactor Foldout No. 7, NU, Jan., '59.

In addition, the following shorter articles have appeared in our pages:

NU Wk, Jan. 26, 1
NU Wk, Feb. 2, 1
NU Wk, Feb. 9, 2
NU Wk, Feb. 23, 3
NU, March, 30
NU Wk, April 6, 1
NU, May, 17
NU Wk, May 11, 2
NU, June, 26
NU Wk, June 15, 2
NU, July, 22
NU Wk, Aug. 17, 4
NU Wk, Sept. 7, 3
NU Wk Sept. 14, 2

roentgens over an indefinite period of time. In part this discrepancy was due to the different amounts of contact with radiation that a man had either received or was likely to encounter in his own job. In our selection of groups of men for jobs involving radiation hazards we considered the ages of the men and chose older men whenever possible.

Evidence obtained during the phase assured us that no immediate danger existed from exposure of the early rescue teams or from contamination to the environment. This evaluation was based on the following:

- The maximum whole-body gamma exposure to members of the early rescue team was 27 roentgens (Table 2).
- Despite existing inversion conditions, contamination to the environment was slight (Figs. 1 and 2).
- Air samples collected at the fence around the site and at the control point gave concentrations of I^{131} $<10^{-9}$ $\mu c/cm^3$.
- Aerial and biological monitoring early on Jan. 4 confirmed these small contamination concentrations beyond the SL-1 area (Fig. 3). The largest activity—125 cps above a 200-cps background—detected by the first aerial-monitoring flight was ~3 miles southwest of the reactor site. The gross gamma count from sagebrush in the same area was <50 times background.

Recovering Bodies

During Phase 3—recovery of the bodies of the two remaining crew members—health physicists set an exposure guide to workers in which ten men would be allowed to reach 10 roentgens during the rescue work (Table 1). Fortunately because of carefully planned and executed team work this limit was never reached. To minimize the exposures three two-man teams were organized to go in the reactor room for not more than 1 min each to recover the second body. All the teams were staffed by Army cadre men who knew the facility; thorough briefings gave them clear pictures of their missions. Fortunately only one two-man team was actually used inside the reactor building.

Because of this careful planning, the first two-man team, which retrieved the first body and descended midway down the stairway within the allotted minute, received whole-body exposures of only 9 and 4 roentgens respectively. Although there were areas on the victim's body that gave 500-r/hr readings at ~1 ft, the second crew, which carried the body as far as the gate house, received only 260 and 305 mr, respectively.

To reduce the radiation levels inside the cab of the ambulance that carried the bodies to the decontamination room at the Idaho Chemical Processing Plant, the crews removed the clothing from both bodies. Although the clothing was wet and very contaminated, removing it did not greatly reduce the general radiation field because of the gamma-emitting particles imbedded in the bodies by the explosion. Therefore the men improvised lead coats as partial shieldings for the bodies; the fireman driving the ambulance the 11 miles to the plant received only a 180 mr dose.

An eight-man medical monitoring team from Los Alamos Scientific Laboratory helped physicians from NRTS decontaminate the bodies to 1–10% of their original levels. This team was a great boon to IDO since by turning over the important decontamination job to someone else, the health physicists in the Health and Safety Division could give their undivided attention to other jobs at the disaster site.

Similar health physics practices were used during the photographic, TV and other entries connected with removing the third body (Fig. 4). During these operations the crews received exposures in the range of 2–6 roentgens.

After the recovery of the third body health-physics responsibilities were gradually shifted from the Health and Safety Division back to the health-physics staff of Combustion Engineering, the operating contractor for the reactor. Since that time their general duties have been to give health-physics support to the remote operations for the SL-1 recovery program. In late May these responsibilities were handed over to General Electric, the SL-1 decontamination contractor.

TABLE 2—SL-1 Exposures >5 r Through Jan. 9

Individual	*Penetrating radiation (roentgen)*	*Thyroid dose from I^{131} (rads)*
AEC health physicist	27	4.2
Contractor supervisor	27*	1.2
Contractor supervisor	25	0.6
Contractor supervisor	25	1.2
Contractor health physicist	23	5.5
AEC project officer	21	0.0
Cadre supervisor	18	2.0
AEC physician	16*	0.5
AEC nurse	15	0.6
Support patrolman	11	0.5
Support health physicist	11	0.4
Cadre supervisor	9	0.7
Support health physicist	7.4	0.6
Army support	5.9	0.0

* Estimated exposure.

What the Health and Safety Division Does for NRTS

To grasp fully the significance and scope of the health-physics program that went swiftly into operation at SL-1, one must understand the unique position held by the Health and Safety Division in the entire AEC complex. Unlike the situation at other sites where contractors take over much of the health-physics operations, it is the job of the division to develop, coordinate and maintain an effective program for conventional safety and radiological safety at NRTS. By taking over this program the division avoids any confusion that might result if the seven operating contractors and varying number of construction companies at NRTS organized independent operations. In connection with its program, the division provides film-badge services, portable survey instruments, fire protection, industrial medicine and bio-analysis although the responsibility for providing common services varies with the installation size and the extent of the operating contractor's health and safety programs. Moreover the division provides environmental monitoring outside the immediate fenced area surrounding each reactor site; the contractors help man the Region 6 radiological assistance teams administered by the Health and Safety Division.

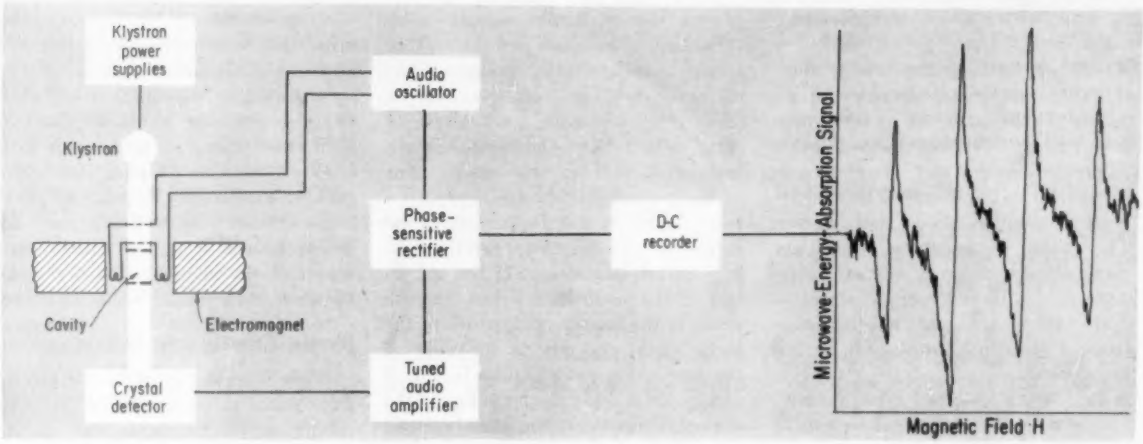

FIG. 1. ESR SPECTROMETER shown in block diagram probes hyperfine structure of methyl radical (trace at right) in solid argon at 4.2°K. Trace is adequately described by Eq. 5 in Appendix in which hyperfine-structure constant A has value corresponding to situation in which free electron occupies 1s atomic orbit of each of three hydrogen atoms in molecule 4% of time

Electron-Spin Resonance Identifies Radiochemical Species

Through their absorption patterns of microwave energy unknown radiochemical intermediates reveal their hyperfine energy-level structures which provide valuable clues to their identities

by EDWARD L. COCHRAN and FRANK J. ADRIAN
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ELECTRON-SPIN-RESONANCE (ESR) techniques have, in recent years, become increasingly useful in radiation research as a means of identifying paramagnetic species involved in radiochemical reactions. ESR [also called electron paramagnetic resonance (EPR)] is in essence a way of detecting unpaired electrons through their interaction with a magnetic field. Thus all radiation intermediates that possess unpaired electrons can, in principle, be studied by this method. These include such species as free radicals, positive and negative radical ions, triplet excited states, free electrons, and electrons more or less stably trapped in crystals.

An atom or molecule with an unpaired electron, when placed in a strong magnetic field, exhibits a hyperfine energy-level structure, which can be described for most situations of interest (see appendix) by the expression

$$W(M_I, M_S) = M_S g_S \beta H_0 - M_I g_I \beta_N H_0 + [A + B(3\cos^2\theta_H - 1)] M_I M_S \quad (1)$$

Here W is the energy difference with respect to the unperturbed state; H_0 is the external field; and θ_H is the angle between the external field and the axis of symmetry of the electron charge distribution; M_I and M_S are the magnetic quantum numbers of a nuclear spin I and the electron spin S. The remaining quantities are constants defined in the appendix on Page 49.

In Eq. 1 the first two terms on the right hand side are the contributions from the interactions of the electronic and nuclear spins separately with the magnetic field. The third term comes from the interaction between the two spins and contains both an isotropic part and an anisotropic part.

On the basis of Eq. 1 we can distinguish three types of ESR spectra, each of which has been important to

the study of the effects of high-energy radiation:

- single-crystal spectra. The individual paramagnetic species are all oriented in the same way by the crystal field, and $A + B(3\cos^2\theta_H - 1)$ has a different value for each orientation of the crystal in the magnetic field.
- polycrystalline solids and glasses. The various paramagnetic species are randomly oriented relative to the magnetic field. Here hyperfine structure is due to A in Eq. 1 with the anisotropic term contributing only to line broadening.
- fluid-media spectra. The quantity $(3\cos^2\theta_H - 1)$ is averaged to zero by the rapid tumbling of the paramagnetic species resulting in a sharp-line hyperfine structure contributed by A alone.

Experimental Technique

One investigates the magnetic energy level structure of an unknown species by subjecting the sample to an a-c electromagnetic field. A resonant increase in the energy absorbed occurs when the a-c frequency corresponds to the energy difference between an appropriate pair of levels (see appendix). From Eq. 1 the frequencies for the transitions ($\Delta M_s = 1$, $\Delta M_I = 0$) are

$$h\nu(M_I) = g_a\beta H_0 + [A + B(3\cos^2\theta_H - 1)]M_I \quad (1a)$$

ESR detection is more sensitive the higher the frequency used for observation (see appendix). The size and availability of microwave components have limited most ESR work to frequencies around 9,000 Mc with the corresponding magnetic fields around 3,000 gauss. Figure 1 is a simplified block diagram of a typical ESR spectrometer. The klystron tube converts d-c power to monochromatic high-frequency electromagnetic radiation. This high-frequency radiation travels through a waveguide to an absorption cell (cavity). In the cavity the electromagnetic energy is reflected back and forth several thousand times before it escapes into a second wave guide and reaches the crystal rectifier that serves as a detector. If a paramagnetic sample is placed in the cavity and the whole inserted into a magnetic field, as the magnetic field is slowly changed, the d-c current in the crystal will behave as shown in Fig. 2 (solid curve). The fields at which one observes a decrease in current (that is, an absorption of r-f energy) correspond to solutions of Eq. 1a for the particular sample used.

Because d-c signals are difficult to amplify, one generally modulates the magnetic field at some convenient audio frequency with a set of Helmholtz coils. When the sample is absorbing radio-frequency energy, this audio-frequency field superimposes an audio signal on the d-c current in the crystal which can be amplified by high-gain tuned amplifiers. If the amplitude of the modulation is less than the width of the line, the magnitude of the audio signal depends on the *slope* of the absorption (solid) curve in Fig. 2 and its phase depends on the sign of the slope. Thus if one converts the audio signal from the amplifier to d-c with a phase-sensitive rectifier, one obtains the first derivative of the absorption curve, the dotted curve in Fig. 2.

A major difference between ESR and other forms of spectroscopy is that in ESR the energy levels depend on a laboratory variable—the magnetic field. When searching for energy absorption (resonance) one can vary the magnetic field rather than the frequency of electromagnetic radiation. In other forms of spectroscopy the energy levels are inherent properties of the molecule and one has no choice but to vary the frequency.

Compared to other branches of spectroscopy, a major advantage of ESR is that such techniques as amplification, phase detection, and electronic filtering can be used to achieve remarkable sensitivity. Currently available commercial instruments are capable of detecting 10^{-12}, moles of unpaired electrons in the presence of up to 10^{-1} moles of diamagnetic material. This extreme sensitivity is important in radiation studies, for major changes in properties of materials such as inorganic crystals and biological substances often result from relatively slight chemical transformations.

In applying ESR to radiation studies one must be careful about using materials that have a large dielectric constant; these tend to dissipate the high-frequency electromagnetic energy in the cavity by field-independent absorption and thus decrease the sensitivity. This problem is particularly pronounced for biological specimens that contain a high proportion of liquid water.

A second difficulty arises from the tendency of high-energy radiation to generate paramagnetic centers in the glasses often used as sample holders. This problem can be eliminated by using different containers for irradiation and ESR observations.

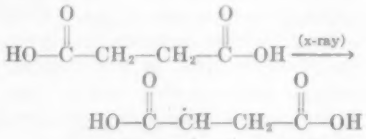
Still another difficulty arises when the experimenter wants to conduct ESR observations simultaneously with charged-particle irradiation. The problem here is that the magnetic field tends to deflect the particle beam. An arrangement to inject the beam through a hole in the magnet pole face along the lines of force avoids this difficulty.

Single-Crystal Irradiation

When inorganic crystals and glasses are exposed to ionizing radiation, optical-absorption bands appear in the visible and ultraviolet regions of the spectrum. These bands lead to problems in the use of windows and other optical devices in conjunction with intense radiation sources. This is one of the reasons the so-called "color centers" have received considerable study. Much of this research has focused on alkali-halide single crystals (because of their relative simplicity) and the various centers found have been catalogued according to their spectral properties. In recent years ESR studies have yielded a great deal of detailed information about the nature of these centers. Perhaps best understood is the F-center, which is produced when an electron is trapped by a negative-ion vacancy. The wave function for this electron extends over several nearest-neighbor distances and both isotropic and dipolar coupling constants (A and B in Eq. 1) have been measured for several shells of adjoining nuclei (*4*).

ESR techniques are also being used to investigate the kinetics of thermal and photolytic bleaching of color centers. Radiation-induced magnetic centers in various other inorganic crystals of practical interest such as quartz, germanium, and silicon are also under study.

The first comprehensive studies of paramagnetic species in organic single crystals have appeared only very recently. As an example, Heller and McConnell (*5*) have recently irradiated single crystals of β-succinic acid with x-rays to form free radicals as follows



They found that the free radical was oriented in the irradiated crystal in nearly the same way as the parent molecule was oriented in the undamaged crystal. The α proton (i.e., the proton in the $-$CH-unit) gave a highly anisotropic splitting (B comparable to A in Eq. 1) while the two β protons (in the $-CH_2$-unit) gave nonequivalent isotropic ($A \gg B$) splittings of 80–100 Mc. Work of this nature is exceedingly helpful in interpreting the more complicated spectra that result from irradiating complex molecules in polycrystalline form.

No electronically excited radiation intermediate has thus far been detected by ESR techniques. There is, however, a recent report on the ESR spectrum of naphthalene in the lowest triplet excited state obtained with ultraviolet irradiation (*6*). The naphthalene was contained in a single crystal of durene to reduce the effects of magnetic anisotropy. We can expect that in the near future similar long-lived excited states will be detected during high-energy irradiation.

Polycrystalline Solids

Experiments on polycrystalline solids are considerably easier to perform than single-crystal experiments, but are usually much more difficult to interpret. As a result there exists a large amount of ESR data on irradiated polycrystalline solids (and glasses) that are incompletely understood. Experiments of this type do give relatively simple results, however, for S-state atoms, and for small radicals that can rotate fast enough to average out magnetic anisotropies. Thus hydrogen and nitrogen atoms have been observed under gamma irradiation with Co^{60} in solid hydrogen and nitrogen respectively. CH_3 and other small hydrocarbon radicals have also been observed in samples irradiated with gammas at

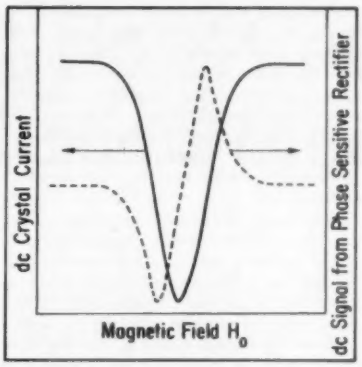


FIG. 2. ESR SIGNAL in absence of field modulation (solid) and with field modulation and phase sensitive detection (dotted)

low temperatures, and irradiated ice has yielded spectra attributed to hydrogen and hydroxyl radicals as well as other still unidentified spectra (*2*). The methyl-radical spectrum shown in Fig. 1 is typical of the ESR spectra observed for small radicals in polycrystalline matrices. Here the three equivalent protons interact with the unpaired electron to split the resonance into four equally spaced components.

Irradiated plastics have received considerable attention. These materials generally give resolved spectra, some of which gradually disappear on standing, and others that appear to be stable indefinitely. Often a sample irradiated in a vacuum will show dramatic and sometimes reversible changes in its ESR spectrum when exposed to air or various other gases. Much remains to be done to relate the observed ESR spectra to radiation degradation and crosslinking. Of particular interest is the question of whether in some instances the observed spectra are due to trapped ions (*Ref. 2, ch. 14*).

ESR resonances are also produced in irradiated biological materials such as hair, bone and feathers, and simpler substances such as dehydrated proteins. These resonances are generally broad with little or no resolved structure, but it seems possible that systematic studies which use specialized techniques will eventually yield useful information.

Irradiation of Fluids

One of the advantages of studying ESR spectra in fluid media rather than in solids is that the magnetic anisotropies average out; this often results in a greatly simplified spectra. Isotropic hyperfine interactions are still present, of course, and these usually suffice to identify the radical. From the point of view of the radiation chemist, observations in fluid media, where paramagnetic species are free to diffuse and react, open up a whole new field of radiation kinetics.

The main difficulty in experiments of this type is that of obtaining sufficiently large steady-state concentrations of the radical. This problem becomes more acute as the reactivity of the radical increases. With the gradual improvement in the sensitivity of the ESR technique, however, Fessenden and Schuler have been able to observe ethyl radicals in liquid ethane under electron bombardment (*7*). Experiments of this type should greatly increase our understanding of the fundamental processes of radiation chemistry.

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APPENDIX

Electron-Spin Resonance—What Is It? How Is It Used?

To understand how ESR works, consider first a free electron with spin angular momentum S. This spinning charge generates a magnetic moment

$$\mu_S = -g_S\beta\mathbf{S}$$

where g_S is a dimensionless constant whose value is 2.0023, β is the Bohr magneton and $\mathbf{S}$ is in units of $h/2\pi$.

If the electron is placed in a magnetic field $\mathbf{H_0}$, μ_S (and hence $\mathbf{S}$) will be quantized with respect to $\mathbf{H_0}$. If $\mathbf{H_0}$ is along the z-axis of the laboratory coordinate system, the Hamiltonian for the magnetic energy of the electron is

$$H = g_S\beta\mathbf{S}\cdot\mathbf{H_0} = g_S\beta S_z H_0$$

This has the energy levels

$$W = g_S\beta H_0 M_S$$

where M_S is the magnetic quantum number, which for an electron can take only the values $\frac{1}{2}$ and $-\frac{1}{2}$. Thus there are two magnetic energy levels, $W_{\frac{1}{2}}$ and $W_{-\frac{1}{2}}$, separated by $g_S\beta H_0$ (see Fig. 3). Transitions between these levels can be stimulated by an a-c electromagnetic field of fre-

quency ν_0 such that $h\nu_0 = g_S\beta H_0$. Thus the ESR of a free electron can in theory be observed at any frequency, provided the magnetic field has a suitable value.

The relative population of the energy levels shown in Fig. 3 is given by the usual Boltzman relation

$$\frac{N_{\frac{1}{2}}}{N_{-\frac{1}{2}}} = e^{\frac{-h\nu_0}{kT}} \qquad (2)$$

where $N_{\frac{1}{2}} + N_{-\frac{1}{2}} = N_0$, the total number of unpaired electrons.

Because the a-c electromagnetic field stimulates spin transitions from the lower energy level to the upper level and vice versa with equal probability, the net energy absorbed from the electromagnetic field will be proportional to the difference in population between the upper and lower levels. For highest sensitivity, therefore, one maximizes this population difference by using the highest possible ν_0 (and corresponding H_0). Equation 2 shows that an alternative way to increase sensitivity is to decrease the sample temperature.

Hyperfine interactions. So far we have been dealing with the ESR of free electrons (a situation approached experimentally by electrons in the conduction band of a metal and electrons in a gaseous plasma). If the unpaired electrons in the intermediate products of radiochemical reactions behaved in precisely this manner, one could observe them and determine their concentration. But one would not be able to ascertain any information about their environment and so could not distinguish among the various chemical species. Fortunately most atomic nuclei, like the electron, have a spin and an associated magnetic moment. The nuclear magnetic moments are small (about one one-thousandth the electronic magnetic moment), yet sufficiently large to change slightly the magnetic field seen by the unpaired electron.

This magnetic moment gives rise to the hyperfine interaction—the magnetic interaction between the unpaired electron and the nucleus. The hyperfine interaction is a function of the relative orientation of the electronic and nuclear magnetic moments. Because the nuclear moment, like the electronic magnetic moment, is constrained by quantum principles to certain definite orientations, the magnetic hyperfine interaction will split the ESR line into a discrete set of lines, one line for each permissible nuclear orientation. Thus, a typical ESR spectrum consists of a set of lines (the hyperfine multiplet). The number of lines and the separation between the lines often enables the ESR spectroscopist to determine the number and kind of nuclei present in the paramagnetic species being investigated. This information is always a valuable clue to the nature and structure of the paramagnetic species and in many instances suffices for a complete identification.

In practice ESR hyperfine multiplets range from the simple to the highly complex, and their interpretation requires an understanding of the hyperfine Hamiltonian (*1*)

$$H_{hf} = \frac{8\pi}{3} g_I g_S \beta\beta_N \delta(\mathbf{r})\mathbf{I}\cdot\mathbf{S} + g_I g_S \beta\beta_N \left[\frac{3(\mathbf{I}\cdot\mathbf{r})(\mathbf{S}\cdot\mathbf{r})}{r^5} - \frac{\mathbf{I}\cdot\mathbf{S}}{r^3}\right] \qquad (3)$$

[g_I is nuclear g-factor, β_N is nuclear magneton, $\delta(r)$ is Dirac delta function, $\mathbf{r}$ is radius vector between nucleus and electron, and $\mathbf{I}$ is spin angular momentum of nucleus.] In addition to the two terms on the right hand side of Eq. 3, the complete Hamiltonian would have a third term describing the contribution of the orbital angular momentum (L) of the electron to the hyperfine interaction. For nearly all paramagnetic species encountered in radiation research the unpaired electron occupies a nondegenerate orbit (hence $L = 0$); for the sake of brevity we omit this term from discussion. (For a more complete treatment of the hyperfine Hamiltonian see Ref. *2* and *3*.)

Isotropic hyperfine interactions. The first term on the right side of Eq. 3, the "Fermi" or isotropic interaction term, has a nonzero value only when the electron probability density is finite at the nucleus. Often this is the only term in the hyperfine Hamiltonian that need be considered; if this is so the total spin Hamiltonian becomes

$$H = g_S\beta\mathbf{S}\cdot\mathbf{H}_0 - g_I\beta_N\mathbf{I}\cdot\mathbf{H}_0 + \frac{8\pi}{3} g_I g_S \beta\beta_N |\psi(0)|^2 \mathbf{I}\cdot\mathbf{S} \qquad (4)$$

The first and second terms on the right hand side of Eq. 4 are the magnetic (Zeeman) energies of the electron and nucleus, respectively. The last term is the Fermi hyperfine interaction. The expression $|\psi(0)|^2$ is the charge density of the unpaired electron at the nucleus. At the high magnetic fields characteristic of most ESR work (3,000 gauss) the solution to Eq. 4 can be written with sufficient accuracy as

$$W(M_I, M_S) = M_S g_S \beta H_0 - M_I g_I \beta_N H_0 + A M_I M_S \qquad (5)$$

M_I and M_S are the magnetic quantum numbers of I and S, and A is the isotropic hyperfine-structure constant given by

$$A = \frac{8\pi}{3} g_S g_I \beta\beta_N |\psi(0)|^2$$

For the hydrogen atom $I = \frac{1}{2}$ and there are thus four magnetic energy levels. Transitions among them are governed by the selection rules $\Delta M_S = \pm 1$, $\Delta M_I = 0$. Figure 4 shows these transitions for a field separation between adjacent lines of approximately 500 gauss.

Anisotropic hyperfine interactions. The second term on the right hand side of Eq. 3 represents the classical interaction between two magnetic dipoles. If the unpaired electron charge distribution is axially symmetric with respect to the nucleus, this term can be written as

$$H_{dip} = \tfrac{1}{2} B(3\cos^2\theta_H - 1)(3I_z S_z - \mathbf{I}\cdot\mathbf{S})$$

Here θ_H is the angle between the external magnetic field and the symmetry axis of the electron charge distribution. The quantity B is the anisotropic hyperfine structure constant given by

$$B = \tfrac{1}{2} g_S g_I \beta\beta_N \left(\frac{3\cos^2\theta - 1}{r^3}\right)_{av}$$

$\mathbf{r}$ is the radius vector between the nucleus and the unpaired electron, θ is the angle between $\mathbf{r}$ and the symmetry axis, and the average is taken over the spatial part of the electron wave function.

The most significant feature of the anisotropic hyperfine interaction is that it causes the hyperfine splitting to vary with magnetic-field orientation. Consider the commonly observed situation in which the dipolar term is small compared to the isotropic term. Here H_{dip} can be evaluated as a first order perturbation of the energy levels given in Eq. 5. The expression for new energy levels, including the dipolar hyperfine interaction, is Eq. 1, which we introduced at the beginning of the article

$$W(M_I, M_S) = M_S g_S \beta H_0 - M_I g_I \beta_N H_0 + [A + B(3\cos^2\theta_H - 1)] M_I M_S \qquad (1)$$

When the anisotropic hyperfine interaction is not axially symmetric, and/or is not small compared to the isotropic hyperfine interaction the equation for the energy levels becomes considerably more complicated. Even in these instances, however, Eq. 1 gives a satisfactory qualitative picture of the effect of hyperfine anisotropy.

* * *

This work was supported by Bureau of Naval Weapons, Department of the Navy, under NOrd 7386.

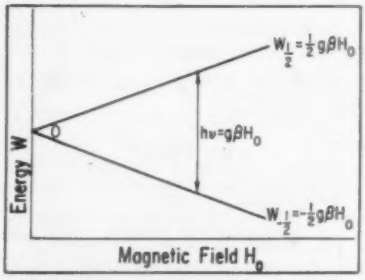

FIG. 3. ENERGY-LEVEL DIAGRAM for free electron in magnetic field

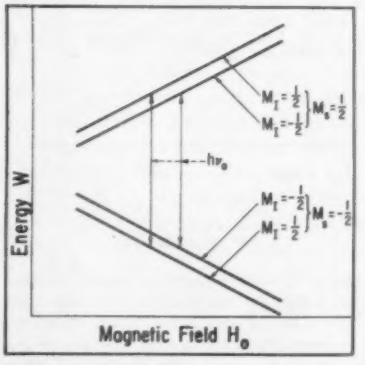

FIG. 4. ENERGY-LEVEL diagram for hydrogen atom in strong field

Large-Area Flow Counters Speed Radiation Measurements

Size and sensitivity (with anticoincidence circuits) of newly developed proportional flow counters open broad vistas for faster and more accurate measurements of alpha and beta particles and gamma rays

by HANS KIEFER and RUPPRECHT MAUSHART, *Nuclear Research Center, Karlsruhe, West Germany*

ALTHOUGH ADVANCEMENTS in electronic portions of radiation monitors have eased and quickened health physicists' routine tasks, the radiation detectors—the very heart of monitors—have not been keeping pace. Thus when we became dissatisfied with available monitoring instruments, we developed a flow proportional detector with a particularly large counter area. This counter offers significant advantages for a variety of radiation-measuring tasks.

Desirable Features

Because we always had trouble with commercial types of flow counters, we compiled a list of the features we believed a new large-area flow counter should have:

- It must be possible to design the effective counting area in various sizes and shapes.
- The detector should count every single alpha or beta particle entering at any one point of the counting area.
- The counter should be usable with or without a window.
- When the counter is used without the window, dust particles must not contaminate the counting chamber by electrostatically adhering to its interior.
- Without the window the counter must be able to count samples of random quality, including electrically nonconductive samples.
- It should be possible to purge the counter within only a few minutes without consuming gas excessively.
- The counter must contain no dead volume (volume should be small compared to area) so that less shielding material is needed and the background count per unit area can be kept low.

Design Concept

To satisfy these needs we have built detectors of wires stretched on circular or rectangular frames (resembling a harp). Facing both surfaces of this counting grid, another grid serves as the cathode. The space between the counting grid and the cathode is very small (0.5–1.5 cm). By suitably spacing the field we keep the response probability constant over the entire counting area. The field is effective

Why Proportional Flow Counters?

Compared with large-area scintillation counters, on which much design and development attention has been lavished, the flow counter offers some considerable advantages:

- Its costs increase much less rapidly with growing size than do those of the scintillation counter.
- Its shape does not have to correspond to that of the photomultipliers.
- It is less temperature-dependent.
- It has a longer life.
- It can be designed for the same effective counting surface with a lower background count.

Flow counters can operate either in the G-M region or in the proportional region, depending on the counting gas used. Because of its simpler electronic circuits, until now the G-M region was selected almost exclusively. But now there is no longer justification to shun amplifiers of high input sensitivity; if the electronic part is satisfactory, the proportional counter clearly is superior to the G-M counter because:

- It permits discrimination against weak background pulses.
- It can discriminate between alpha and beta radiation.
- Inexpensive methane can serve as counting gas.
- Spectroscopy of alpha as well as of soft gamma radiation can be conducted, the latter process being even more favorable than with a scintillation counter.

For all these reasons we believed it important to explore the possibilities of large-area proportional counters. The examples cited here show the setups we worked out and the many possibilities for applying large-area proportional flow counters.

only between the grids; any marginal influence is excluded completely. The grid system is one unit and can be installed in any type box of any material.

System size is practically unlimited (but to keep the wires from sagging if they are stretched across more than 30 cm they must be supported by a stronger lateral wire). The cathode grid keeps the electric field from overlapping to the sample we are measuring, which is placed immediately below this cathode. Thus the sample is within the field-free area, which makes its electrical properties unimportant for our purposes. This also means that we can close the counter below the cathode grid with conductive or nonconductive foils of any thickness. Of course the method we use to distribute the methane flow depends on the counter housing and thus on plans for future use of the counter.

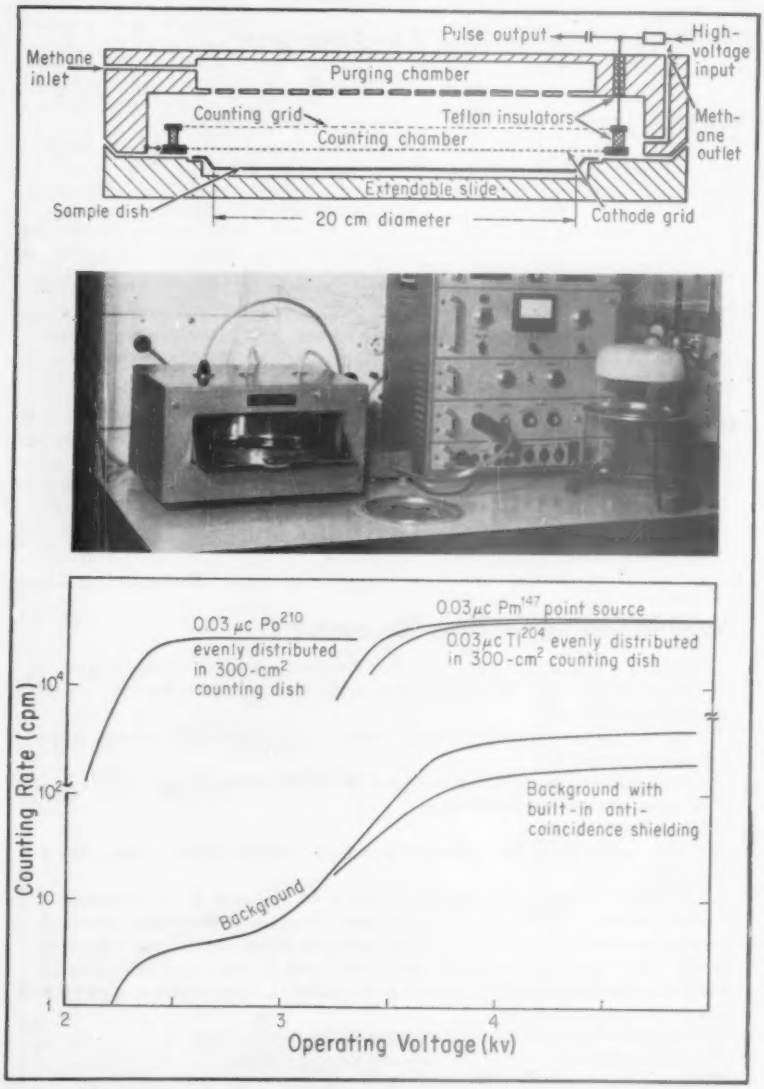

FIG. 1. COUNTER CONTAINS large sample dish that holds residue from evaporation process on water samples. Counting grid consists of 50-micron molybdenum wires spaced 1 cm apart; cathode grid above sample dish consists of 200-micron silver-plated copper wires ½ cm apart; conductive container cover serves as upper cathode. With technically pure methane, operating voltage is ~4 kv for betas, ~2.5 kv for alphas. With suitable amplifiers, plateau slopes less than 1 %/100 v over 1,000 volts. If chamber is shielded by 3 cm of lead on all sides, at working point for beta radiation the background is ~250 cpm (0.8 cpm/cm² counting area)

Alphas, Betas in Water

Figure 1 shows the circular counting system we built to count total alpha and beta radioactivity in solid residue from an evaporation process. The flat configuration and the lack of marginal effects give a particularly low specific background (0.8 cpm/cm² counting area).

Why large area? For measurements of total alpha and beta radioactivity in water the large area of the sampling dish gives advantages both in quick sample preparation and in small self-absorption. The large water surface permits short evaporation time (75 min/liter), which cuts the labor involved in preparing many samples (*1*). By using infrared heat to evaporate water directly in the counting dish we avoid the wall-absorption losses that are inevitable if we use a separate container for evaporation (*2*). Large surfaces are important also when the activity from the water is concentrated by coprecipitation or adsorption (*1*) rather than by evaporation. With these methods, chemicals deliberately added to the water always cause more residue (2–3 gm/sample). Compared to evaporation, these chemical processes offer the advantage of processing larger amounts of water in a much shorter time—and thus raise sensitivity (*1, 3*).

Alphas and Betas in Air

Because the maximum permissible concentration for alpha emitters is only 4×10^{-14} μc/cm³ air (*4*), we must filter ~1,000 m³ of air to get fairly accurate samples. On the one hand, it takes filters of several times 100 cm² surface to make these amounts of air free from dust within a reasonable period of time (<24 hr); on the other hand, the dust residue in 1,000 m³ of air is considerable (a few grams). Both facts again show the need for a large-area counter. Because air filters are always made of nonconductive materials, the counter properties must not depend on the electrical properties of the sample.

Monitoring Liquid Waste

Large-area counters open up entirely new possibilities for monitoring water continuously and directly (*5*). Because of its flat shape the counter easily

can be installed directly above the water surface without being contaminated by activity in the water. The large area and the possibility of using very thin windows—in contrast to immersion counters—permit us to detect continuously even low-energy beta emitters like C^{14} and S^{35} below their maximum permissible concentrations.

Devices that work without concentration and that directly indicate beta activity have to use layers of water—saturation thicknesses for most beta emitters—to be sufficiently sensitive. Thus they are so energy-dependent that even with extremely thin counter walls various nuclides of the same maximum permissible concentration (same toxicity) yield counts that differ by several orders of magnitude. So one cannot expect absolute values from equipment that measures directly. But it can give a "yes-or-no" signal before any nuclide reaches its maximum permissible concentration. Figure 2 shows the sensitivity of large-area counters for this purpose.

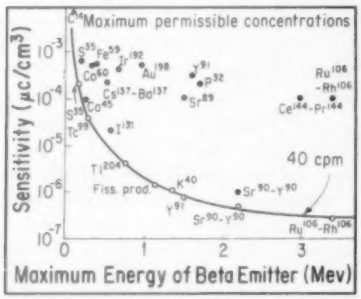

FIG. 2. SENSITIVITY of large-area (~700 cm²) counter for continuously monitoring beta activity of water contamination; in this case counters are arranged rectangularly and 0.9-mg/cm² foil covers window facing water surface. Sensitivity curve represents 40 cpm after background is subtracted by a compensating counter

Users of sensitive large-area counters must compensate for background variations that occur under different atmospheric conditions (especially rain) or originate in nearby reactors, cyclotrons or strong radioisotopes. At Karlsruhe we use a differentiation device consisting of two identical counters arranged above the water in such a way that both counters show the same background, but one also detects the radiation from the water. The background counting rate is subtracted electronically, resulting in the correct water count.

Alpha activity in water also can be monitored by these large-area counters (*3*). No differentiating circuit is needed because in the alpha plateau the background is extremely low and is practically not influenced by outside variations. Sensitivity is sufficient for monitoring all important alpha emitters (except Ra^{226}) below their maximum permissible concentrations.

Monitoring air. For continuously monitoring airborne activity we can double sensitivity (at the same background level) by placing a foil on both sides of the counter used for monitoring water.

Monitoring Surfaces

Because the instrument is a proportional counter, we can monitor both alpha and beta contamination on hands separately but simultaneously by electrically discriminating among pulse heights. For monitoring laundry, we position two counting units (with a single 700-cm² window in each) above the garment and two beneath it and pull the garment between them. With a counting-rate meter for visual indication, less than 0.01 μc of even soft beta radiation (equally distributed over the entire garment) can be detected quickly (~10 sec) (*6*). Figure 3 shows a similar counter (but with a double window). Such counters would be particularly useful for continuously and sensitively

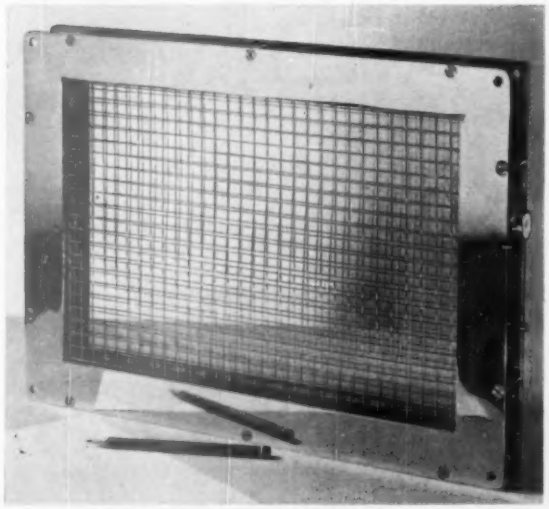

FIG. 3. AIR MONITOR, especially designed for continuously monitoring I^{131} in exhaust stacks, has double window (0.9 mg/cm²) of 1,400 cm² total surface. Protective grids (that keep thin-foil window from blowing out if gas pressure surges) on each side of counter are readily visible; cathode wires are barely visible, but counting wires are too fine to see here. With single window, same unit monitors alpha and beta contamination

FIG. 4. TO MEASURE PLUTONIUM in an arm, one large-area cylindrical flow counter surrounds another (linked by an anti-coincidence circuit that partly compensates for background). With a point source of 5×10^{-10} curies of plutonium inside this experimental counter, a count on a gamma line of plutoninm is twice the background; on this line we can achieve discrimination factors of 200 against Ra^{226} and 120 against Cs^{137}

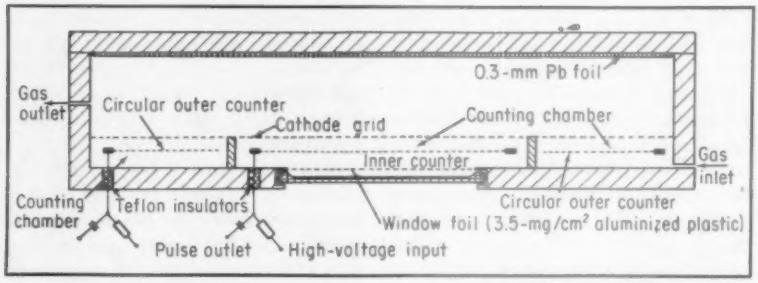

FIG 5. IN BACKSCATTER COUNTER for determining beta energies center chamber counts primary betas from sample (in 20-cm dish); then lead foil on lid scatters some betas back into annular counter chamber. Counter diameter is 60 cm; altogether, length of counting wires is ~16 meters

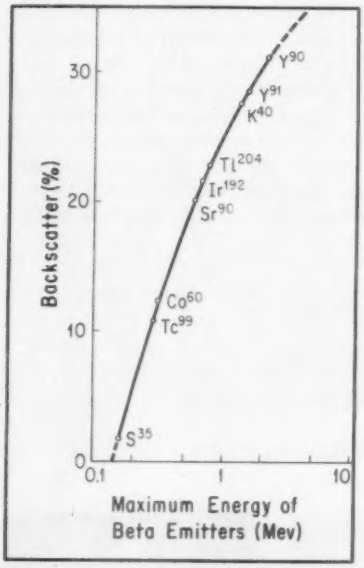

FIG. 6. BACKSCATTER COUNTER calibration curve experimentally recorded for a series of beta emitters

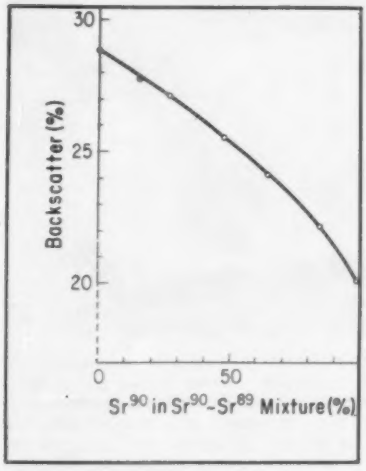

FIG. 7. BACKSCATTERING as a function of Sr^{90} content in a Sr^{89}-Sr^{90} mixture

checking packaging materials for photosensitive films.

Low-Level Betas

Where a large-area counter serves as a protection counter in an anticoincidence circuit it offers the advantage that there is only a single counter with a completely uniform shielding effect across the whole surface—instead of a number of single counters that might have to be adjusted in different ways. Because it is flat this device and its shield can be kept small. For instance one such counter (*7*) needs <100 kg of lead to reach a specific background of less than 0.1 cpm/cm². Specific background is nearly independent of the monitoring-counter size.

These large-area counters can reduce the effective cosmic radiation in shielded counting rooms (or in the steel chamber of a body counter) if they are mounted above the working surface (or along the entire ceiling of the counting room) and then all equipment in the area is operated in an anticoincidence circuit with these shielding counters. To our knowledge, A. Malvicini of Ispra, Italy, first applied this idea with liquid scintillators.

To learn whether construction materials for radiation detectors and shields of body-counting devices or anticoincidence equipment are free from radioactivity, at Karlsruhe we use a very large 4π setup whose two parts are operated in an anticoincidence circuit with each other (*7*). With 10-min counting time we can detect activity corresponding to a surface contamination of 10^{-14} c/cm² with 20% accuracy.

Spectroscopy

Their size makes these counters suitable for spectroscopy of alpha particles and low-energy gammas (*8, 9*). Because the material to be monitored can be spread out in a very thin layer the large area is particularly helpful for measuring alphas. However, it is advisable to use a denser gas than methane (perhaps argon) as counting gas.

Figure 4 shows low-energy-gamma spectroscopic device for assaying incorporated plutonium.

Determining Beta Energy

Figure 5 shows a large-area proportional counter for rapidly determining the beta energies of any emitter by means of backscattering (*10*). The fraction of betas that scatter into the annular counter directly indicates the energy of the primary betas. To minimize the background effect of the outer counter—which has a very large surface—the inner and outer counters operate in a coincidence circuit. Thus the outer counter registers only pulses that already have been counted in the inner counter. Figure 6 shows the calibration curve for this counter. In the normal use of this counter a single counting operation determines the sample activity and also gives a hint as to the type of beta emitter in the sample. But this device can do even more. For instance, Fig. 7 shows how the concentration of Sr^{90} in a Sr^{90}-Sr^{89} mixture can be determined immediately. This type of measurement is especially useful where possible danger from fission products must be estimated quickly; it also can be used to help control the purity of isotope solutions or to determine the age of fission products.

* * *

License for manufacturing these flow counters is held by H. Kimmel, Firma Münchener Apparatebau für elektronische Geräte, Osterwaldstrasse 69, München, Germany.

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Construction of Consumers Power Company's Big Rock Point Nuclear Plant is more than 60% complete. Criticality of the 50,000-kwe, direct-cycle, forced circulation boiling water reactor is scheduled for October 1962.

SYMBOL OF NUCLEAR PROGRESS

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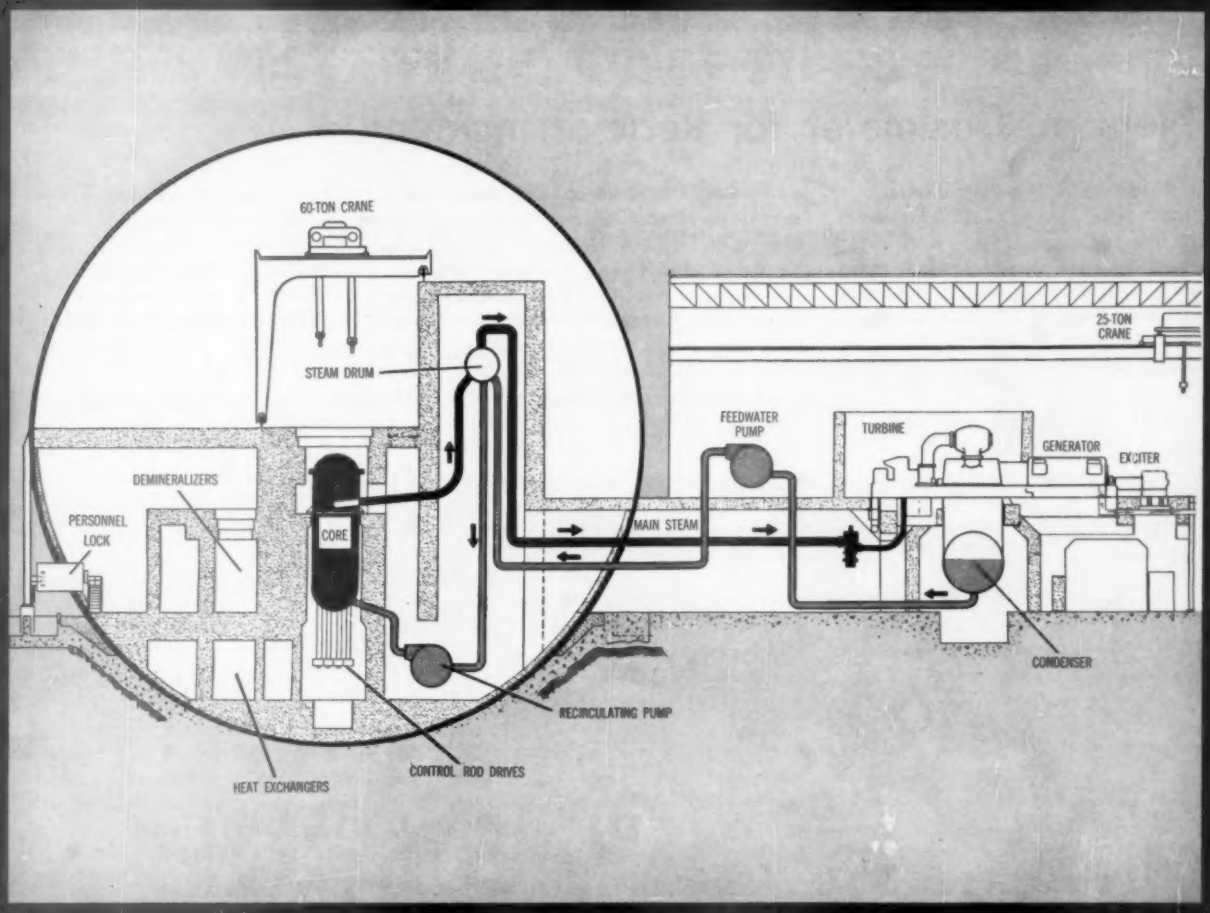
Big Rock Point will develop important nuclear technology—high power density, increased fuel lifetime, and improved fuel fabrication techniques for high performance nuclear fuel.

Consumers Power Company will make this plant available for a 4½-year research and development program to be conducted by General Electric for the Atomic Energy Commission. This program already is underway in several areas:

- fuel fabrication development
- irradiation of experimental fuel in General Electric Vallecitos Boiling Water Reactor
- analytical and experimental work to predict reactor heat transfer and stability performance under a wide variety of plant operating conditions
- analytical studies to achieve improvements in reactor performance by determining optimum core power, fuel burnup and refueling scheduling
- specification of a computer to calculate control rod position for optimum core burnup under varied operating conditions
- preliminary design studies of a 300-mwe high power density boiling water reactor plant

Progress In Nuclear Technology Helps Keep Power Costs Low

Dresden—
Large Boiling
Water Reactor Feasibility
(Commonwealth Edison Co.)



General Electric is supplying the nuclear steam supply system, fuel, turbine-generator, and major electrical components. Bechtel Corporation is engineer-constructor and prime contractor for the plant.

This program will continue during the first four and one-half years of Big Rock Point Plant operation—until 1967.

An ultimate goal for Big Rock Point is to raise its initial electrical output from 50,000 kwe to 75,000 kwe. To do this, the reactor core will be tested at average power densities of 45-60 kw/liter—twice the power density of the Dresden Station, and almost double that of large plants now being offered.

Higher power density will mean more power output from a boiling water reactor plant per ton of steel and cubic yard of concrete, thereby reducing plant capital cost-per-kilowatt. Improved techniques for fuel fabrication will help reduce the cost of high-performance nuclear fuel. The result of these efforts will be lower plant power costs.

Big Rock Point is an essential link in the development of large economical boiling water reactor nuclear power plants. Achievement of the high power density goals is a key step in bringing closer the widespread use of nuclear-electric power in line with the objectives of the utility industry and those of the Atomic Energy Commission's power development program. After the research and development phase of Big Rock Point is completed, the plant will become a dependable part of Consumers Power Company's electrical system supplying needed power to northern Michigan.

For more information about the technical development program for boiling water reactors, contact your General Electric Generation Sales Representative or write to General Electric Company, 1 River Road, Schenectady, New York. Outside the United States and Canada, write to International General Electric Co., 159 Madison Ave., New York 16, New York. 132-14

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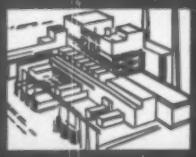
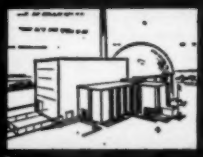
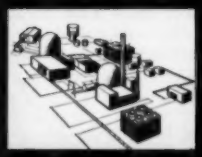


Humboldt Bay—Natural Circulation, Pressure Suppression (Pacific Gas & Electric Co.)



Big Rock Point—High Power Density (Consumers Power Co.)



ESADA—Nuclear Superheat (Empire State Atomic Development Associates)

Neutron Dosimeter for Reactor Incidents

Savannah River has developed a small, pencil-shaped neutron dosimeter to monitor extreme doses received by reactor operating personnel in event of a criticality accident.* Ordinary neutron-sensitive film and ionization devices are capable of measuring exposures only up to 1 rem, but the dose to a worker in an accident could range from levels of this order up to thousands of times this order depending on the details of incident. To cover his wide range the Savannah River dosimeter detects neutron dose through the activation of an array of neutron-sensitive materials stacked one above the other in the pencil container. The pencil also contains a vial of chemical solution that monitors gamma exposures from 50 r to 10^4 r. In addition work is under way to include a feature that would correct for shielding of the dosimeter by the person wearing it. The cost of the dosimeter is expected to be less than $5.00. The dosimeter container is a plastic tube 3⅝ in. long and ½ in. in diameter; the complete assembly weighs only 15.5 gm.

* J. E. Hoy. DP-472 (Sept. 1960).

High-Performance Neutron Counter for EBR-2

To monitor startup operations for Experimental Breeder Reactor-2 (EBR-2) Argonne has developed a neutron-counting system that will process 3×10^5 cps with less than 10% counting loss due to instrument deadtime.* The system is meant to monitor neutron flux at startup over a four-decade range below the point where ion chambers become useless because of their sensitivity to background gammas. (The ion-chamber signal from gammas equals the signal from neutrons at a neutron flux of about 2.2×10^4 n/cm²-sec). If one allows for a one-decade overlap between pulse-counting and ion-chamber systems, then the counting system must be able to function at levels from 2 n/cm²-sec to 2×10^5 n/cm²-sec in the presence of a 3×10^3- r/hr gamma background.

The system developed by Argonne to meet these specifications consists of a fission counter, preamplifier and linear amplifier with an integral discriminator. To meet the stringent requirements, each of the three components was carefully tailored to squeeze out the optimum in performance. The designers found that the Westinghouse Type WX 4245 fission counter contains enough fissile material to provide the required absolute efficiency and that it has a collection time, when operated at 1 atm of nitrogen and argon and 300 volts, of less than 7×10^{-8} sec.

The preamplifier design is a compromise among low noise, gain stability (particularly with respect to temperature variations), radiation and temperature resistance and the desire to have as few components as possible. To achieve stability the preamplifier uses capacitors of ceramic dielectric and resistors made from a high-temperature-deposited carbon film plus either bare or ceramic-insulated connecting wire. The four tubes of the circuit are RCA Tubes Type 7586 (Nuvistor). The gain of the preamplifier circuit shows less than a 5% change for temperature changes from 25°C to 90°C with no observable change in performance during two weeks of steady operation at 90°C.

The linear amplifier consists of two stages of amplification, a cathode follower and a one-tube discriminator. A neutron pulse, after amplification (the first stage has a gain of 75, the second a gain of 50), emerges as a pulse of 0.4-μsec duration and is presented by the cathode follower to the discriminator to be accepted or rejected. The amplifying stages use Tube Type E180F except for the first-stage input tube which is Type 6922; Type E180F was found to have a mechanical resonance at 12 kc which rules it out for the input position. With careful layout and construction methods, the Argonne designers achieved an over-all maximum gain from the preamplifier and amplifier in excess of 5×10^4, including the loss in the short-time-constant circuit between the amplifier output and the cathode follower. Rise time of the cascaded preamplifier and amplifier is less than 0.1 μsec.

* Robert J. Epstein, Donald C. Thompson. ANL-6292 (1961).

MINIATURIZED FAST-NEUTRON DOSIMETER, about carpet-tack size, consists of 0.1-in. by 0.03-in. silicon disc mounted between two electrical contact pins. Device records fast-neutron dosage cumulatively, and, unlike present film dosimeters is insensitive to all other forms of radiation. Dosage is measured in terms of permanent changes in electrical properties of silicon that result from dislocations caused by fast neutrons. Dosimeter developed by Battelle Memorial Institute for U. S. Army Signal Corps is designed as monitor for persons who work around nuclear reactors or who may be exposed to nuclear-weapon explosions or other fast-neutron sources

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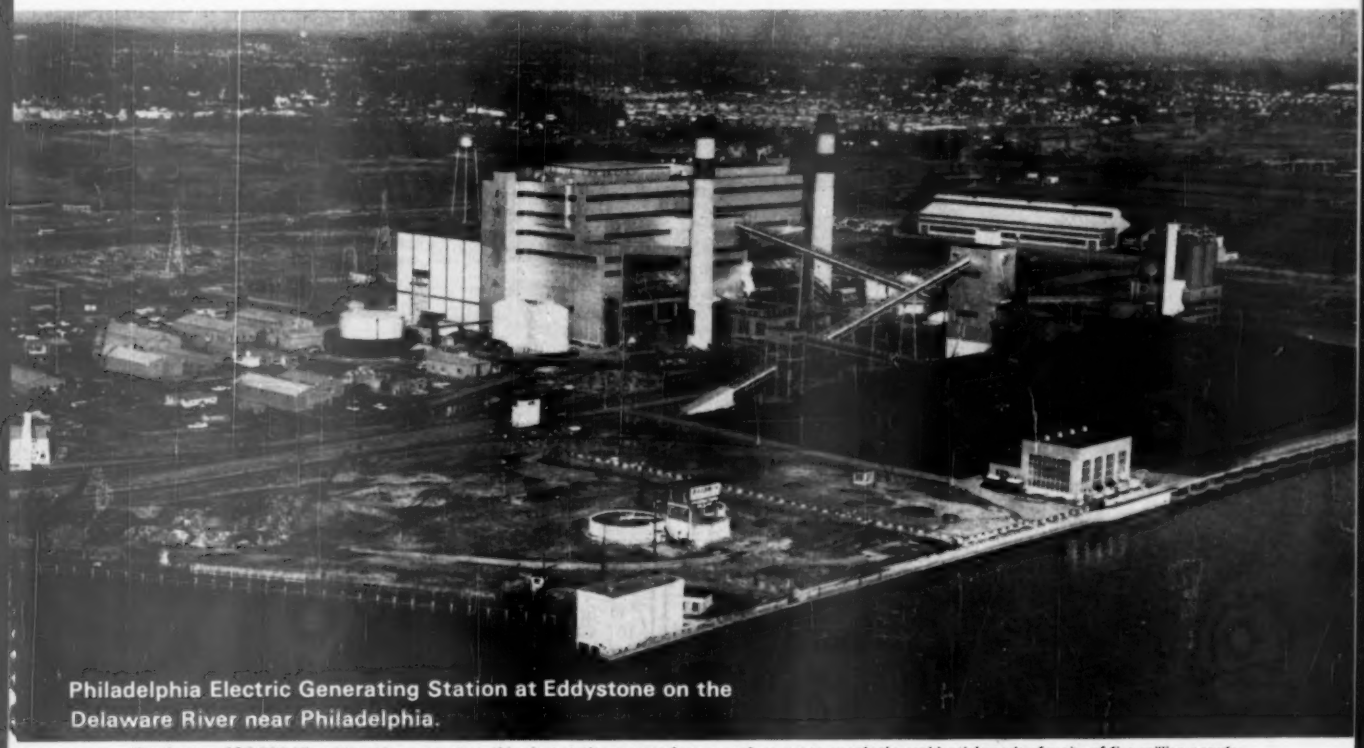

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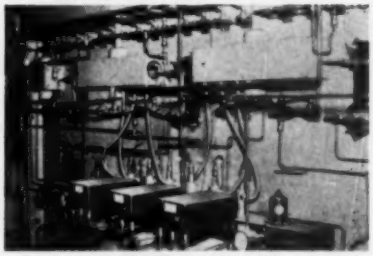

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Vapor-Phase G-M Counters for Studying Isotopic Exchange

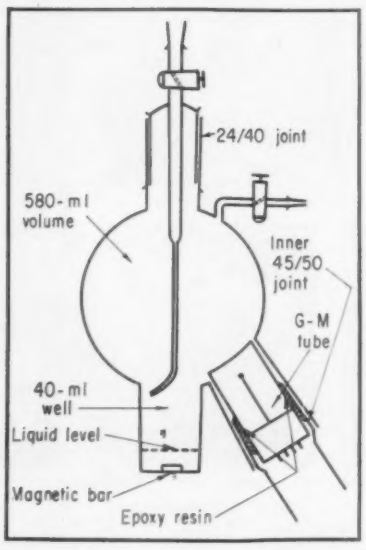
by IRVING M. PEARSON* and CLIFFORD S. GARNER
Department of Chemistry, University of California, Los Angeles 24, California

To follow a radioisotopic exchange reaction—a reaction in which certain molecules exchange isotopes with one another—in a volatile solution, one can continually measure the radioactivity of the gas phase that is in equilibrium with the solution. Then as exchange occurs the change in activity of the gas phase under appropriate conditions is a measure of the exchange reaction rate. For this measurement we developed two reaction vessels, one gun-shaped and one spherical, that can be evacuated and used at pressures as low as 10^{-4} mm Hg with solutions of Cl_2^{36} (0.71-Mev betas) in CCl_4.

For studying exchange reactions at atmospheric pressures Johnson† developed a simple gun-shaped reaction chamber. If, however, one can evacuate the chamber before admitting the reactants and maintain it at a reduced pressure during measurements, one can investigate reaction systems that are sensitive to traces of moisture or air and reactions that must be carried out at temperatures at which the total vapor pressure is considerably less than atmospheric. Since we needed this kind of apparatus in our exchange study we developed our chambers to be evacuated and operated at low pressures.

* PRESENT ADDRESS: Electronics Division, National Cash Register Co., Hawthorne, Calif.

† R. E. Johnson, NUCLEONICS **14**, No. 4, 96 (1956).



SPHERICAL CHAMBER for study of isotopic-exchange reactions has counting efficiency of 0.85% for Cl^{36} betas and can be evacuated

Gun-Shaped Chamber

Our 425-ml gun-shaped vessel is similar to Johnson's except that ours has a tube with a stopcock for evacuating the chamber, a drip-tip delivery tube to carry liquid to the 40-ml chamber well and a 24-mm-diameter mica window cemented to a $^{34}/_{35}$ standard-taper inner joint that is blown onto the chamber coaxially with the "gun" barrel. In developing the design we also tried Pyrex windows; however, since these were too fragile we chose a 4.1-mg/cm² mica window. We also tested soft-setting cements but found that they allow the window to implode or crack when the chamber is evacuated. Therefore we selected a hard-setting epoxy-resin cement.‡ A Nuclear-Chicago Model D-34 G-M tube (1.4-mg/cm² window) mounted close to the chamber window monitors the activity of the vapor phase in the vessel.

We have evacuated the chamber to $\sim 10^{-4}$ mm Hg and can pump on it for hours without damaging the window. Moreover the chamber does not leak even after 2–3 months. Nevertheless because of poor geometry the counting efficiency is small despite the large vapor volume that favors Cl_2 evaporation. For example a solution in the chamber well with ~56% of all Cl_2 and ~3% of the CCl_4 in the vapor phase gave a net count of 134 cpm. We subsequently removed all the Cl_2, hydrolyzed it to get nonvolatile species and dip-counted it with a Nuclear-Chicago Model D-52 G-M tube under geometry and absorption conditions that correspond to a counting efficiency of ~1.4% for Cl^{36} betas. The hydrolysate gave 828 net cpm, corresponding to a chamber counting efficiency of 0.41%, [1.4(134 × 100/56)/828].

‡ No. LHC-14, Cycleweld Cement Products, Trenton, Mich.

Spherical Chamber

To improve the counting efficiency we built a 580-ml spherical reaction chamber (see figure). We cemented a Nuclear-Chicago Model D-34 G-M tube with epoxy resin into a $^{45}/_{50}$ standard-taper inner joint that we then inserted into an outer joint blown onto the chamber bulb. As the figure shows, because of its position the G-M counter does not receive beta radiation from the solution in the chamber well. Except for the window the G-M counter is entirely coated with epoxy resin to prevent reaction with the gas in the chamber. This chamber withstands essentially the same evacuation and leak tests as the gun-shaped one.

As we did with the gun-shaped chamber, we compared the vapor-phase counting of samples in which ~67% of the total Cl_2 and ~5% of the CCl_4 were in the vapor phase with dip-counting of hydrolysates of the total Cl_2. Results show that the dip-counting gave only 2.5 times as many counts per min as the vapor-phase counting; thus the chamber counting efficiency is 0.85%—nearly as efficient as the dip counting. We attribute this improved counting efficiency mainly to the better geometry of the spherical chamber. An added advantage of this chamber is that a mica window does not need to be sealed onto the chamber.

We lubricated the stopcocks and ground joints in these two vapor-phase counters with Halocarbon grease. Since the grease—as well as other vacuum greases and waxes, including silicone stopcock grease—reacts with Cl_2 and absorbs it to some extent, some Cl_2 is lost and a memory effect may occur. If one avoids excessive lubrication, however, the memory effect can be kept to less than twice the background counting rate (~25 cpm with partial lead shielding). For experiments in which Cl_2 is used in these vapor-phase counters, however, it is preferable to use greaseless vacuum stopcocks and conical Teflon sleeves for the joints.

* * *

This work was supported by U. S. AEC under Contract AT(11-1)-34, Project 12.

2 nanoseconds/cm: impossible to photograph until now

Polaroid has a new film that is so fast, it will reproduce scope traces that are almost invisible to the naked eye. The one above, a scintillation pulse, has never been photographed until now. Pulse duration was ten nanoseconds. Scope sweep speed was 2 nanoseconds/cm. *The new 10,000-speed Polaroid PolaScope Land film produced a finished usable print ten seconds after exposure.*

The maximum writing speed of the 10,000-speed film is about twice that of the Polaroid Land 3000-speed film, which is currently the standard for high speed photography. The new film not only gets "impossible" pictures, it also produces far better shots of slower pulses and steady state waveforms. Because of its high speed, less light is required; camera aperture and scope intensity can be reduced considerably, producing sharper pictures.

And besides oscillography, the PolaScope film opens up new possibilities in applications where light is at a premium, such as photomicrography and metallography. It is not suited, however, for pictorial work due to its high contrast and relatively coarse grain.

PolaScope film (designated Type 410) is packed twelve rolls to a carton. The price is actually lower than the 3000-speed film.

The film can be obtained through industrial photographic dealers. For the name of the dealer nearest you, write to Technical Sales Department, Polaroid Corporation, Cambridge 39, Massachusetts.

New Polaroid Land 10,000-speed film for oscillography.

Measuring Detector Deadtimes Accurately

by SVEN GÖSTA RUDSTAM, *European Organization for Nuclear Research (CERN), Geneva, Switzerland*

In making precise determinations of high counting rates one must correct for the events that occur within the deadtime of the detector system and hence are undetected. An accurate correction can be made only if the deadtime is well known.* The traditional methods of measuring deadtime, however, give values good to only 10%. I present here a simple method of determining deadtimes with a tenfold improvement in accuracy.

One can measure the deadtime of the *electronic part* of the counting system with a double-pulse generator that has a variable interval between pulses. But for practical purposes the over-all deadtime is the important quantity—the counter tube or scintillation detector must be included in the deadtime measurement. The over-all deadtime is customarily determined in one of the following ways:

- With a strong sample in the counter the deadtime can be estimated visually with an oscilloscope (*2*). The shortest interval between two pulses big enough to be counted is the deadtime.
- In common use is the method of paired sources (single or multiple pairs) (*3* and *4*) which compares the sum of the counting rates of the sources taken separately with the rate obtained by counting the sources together. This method depends on measuring relatively small differences between large numbers and hence yields accurate results only with difficulty.
- The method of proportional sources uses a set of sources with known relative strengths. One neglects the coincidence loss for the weaker sources, and, from the specific counting rates of these sources, deduces the coincidence losses for the strong sources. A special case of this method is to use the decay of a nuclide with well known half-life.

It is quite difficult to determine the deadtime accurately with any of the above methods. Usually the uncertainty is ~10%. I propose here a straightforward extension of the method of proportional sources that gives the deadtime graphically with great accuracy, easily within 1%. Because the deadtime determination is also very simple to carry out, the method appears superior to those mentioned above. It differs from the usual method of proportional sources in the treatment of the measured data.

If we assume that a count leaves the counter insensitive for the time τ, the corrected counting rate N is obtained from the measured counting rate A by the formula

$$N = \frac{A}{1 - \tau A} \qquad (1)$$

The corrected counting rate is proportional to the strength of the sample. Thus, with q equal to the disintegration rate, N can be written

$$N = Kq \qquad (2)$$

where K is a proportionality constant.

Equation 1 can now be written

$$\frac{A}{q} = K - K\tau A \qquad (3)$$

By plotting A_i/q_i *versus* A_i for a series of samples, we obtain a straight line with its intercept for zero counting rate equal to the proportionality constant K and its slope equal to $-K\tau$. Thus, the deadtime τ is obtained from dividing the slope by the intercept.

Sample preparation. To use this analysis one must prepare a suitable series of samples. It is not necessary to determine the absolute disintegration rates of the samples, but only some quantity proportional to the disintegration rate. For a gamma counter the samples are easily prepared. If a well-type scintillation counter is the subject of investigation, for instance, different amounts of a tracer solution can be pipetted down into a number of sample tubes. Because the gamma counting rate is little influenced by scattering effects, one can also prepare a set of samples by evaporating pipetted or weighed amounts of a tracer solution on discs of aluminum.

This method is not recommended for making a set of samples to determine the deadtime of beta counters because of the troublesome self-scattering effects in beta sources. In this instance a convenient approach is to use electrospraying (*5*). Samples made from carrier-free solutions by this method are very evenly spread, and the self-scattering and self-absorption effect is very small. The amount of liquid sprayed is not known, but if the tracer decays by gamma radiation in addition to beta-particle decay, the samples can be easily calibrated by gamma counting.

For accurate work the self scattering effect, although small, should be taken into account. To do this, one can first count the samples close to the window

* See Reference 1 for details of how NUCLEONICS readers may obtain a special slide rule that computes deadtime corrections.

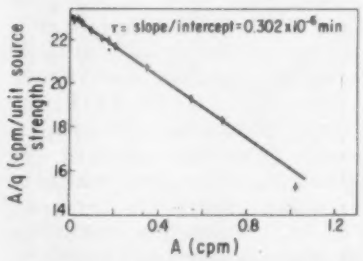


FIG. 1. COUNTING RATE plotted against counting rate per unit source strength gives deadtime τ to within 1% accuracy

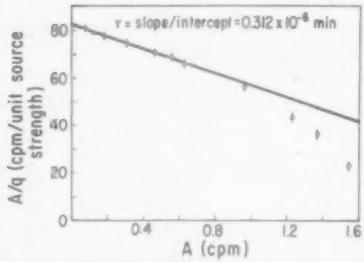


FIG. 2. LINEAR RELATIONSHIP (Eq. 1) for deadtime does not hold for counter tested at rates above 6×10^5 cpm

of the counter and then far from the window, where the coincidence loss is small. The data from the first count are used, together with the gamma counting rates, to determine an approximate deadtime that neglects self-scattering and self-absorption in the samples. This deadtime is used to correct the data from the second count, which then represent relative beta-emission rates. These relative beta rates are combined with the results from the first count to give a more accurate deadtime determination. Further approximations are possible but hardly necessary.

Deadtime studies. Figure 1 shows the results of an analysis by the method proposed here of the deadtime for a flow-proportional counter with methane as counting gas. In this instance the deadtime was found to be 18.1 μsec with a standard deviation of ±0.9%.

For very high counting rates Eq. 1 may no longer be valid. Figure 2 shows a deviation from the linear behaviour corresponding to an increase of the deadtime at counting rates above 600,000 cpm for the flow-proportional counter used. Thus the method described in this article also clearly indicates in which region Eq. 1 is applicable. In this particular test we found that the deadtime was determined by the electronic part of the counter and not by the counter tube itself.

To investigate the possible effect of beta energy on deadtime, we prepared three sets of samples; one contained Nb^{95} (beta energy 0.158 Mev), the second Cs^{137} (average beta energy 0.56 Mev) and the third Ru^{106} (average beta energy 3.3 Mev). The deadtime was 17.4 ± 0.5 μsec for Nb^{95}, 18.1 ± 0.2 μsec for Cs^{137} and 19.0 ± 0.2 μsec for Ru^{106}; thus there is a very small increase in deadtime with increasing beta energy.

Instead of preparing a set of samples, one can follow the decay of a sample with known decay constant. The strength of the sample at different times t is simply obtained as $q = e^{-\lambda t}$. Because the same sample is always counted, the scattering and absorption factors remain constant and will therefore not influence the deadtime determination.

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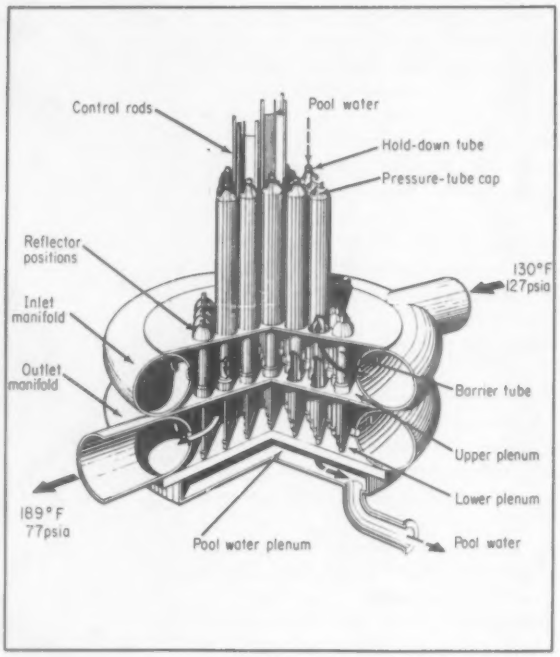
With Pressure Tubes: 25–40-Mw Pool Reactor



COOLANT WATER FLOWS from inlet manifold up outer annulus in 6-tube fuel element (where it is heated to 169°F at 108 psia) and then back down inner annulus to outlet manifold. Pressure tube (aluminum, 37 in. long, 3.5 in. o.d., ⅛-in. wall) around outer annulus and its cap separate coolant water from pool-water; fourth fuel tube (from center) serves as barrier between upward- and downward-flowing coolant. Small amount of pool water flows down within 1-in. unfueled central hold-down tube in each fuel element (samples can be irradiated within this central tube or between adjacent pressure tubes). Double-plenum assembly also serves as grid plate.

With PTR's low coolant flow, and without the need for a costly pressure tank, AMF believes this new reactor will cost only half as much as the $2-million tank-in-a-pool Oak Ridge Research Reactor (this ORR cost includes the reactor, pressure vessel, cooling system, experimental facilities, instruments and controls, but does not include the pool, building or land)

To raise power levels of flexible pool-type research reactors from the present ~5-Mw limit to 25–40 Mw AMF Atomics suggests placing pressure tubes around the fuel elements so they can operate hotter without boiling the coolant water. With the coolant in a closed system separate from the pool water, there is no problem of making pool water excessively radioactive. Further, with a tubular fuel element from which a two-pass flow of coolant removes heat, total coolant flow can be kept low.

To develop this pressure-tube reactor (PTR) concept AMF has conducted 96 critical-experiment runs and now is flowtesting fuel and pressure tubes.

Critical experiments. Even with its tubular fuel elements the PTR core contains nearly the same fractions of water, aluminum and uranium as a typical pool reactor. But, to verify calculations, between July 7 and 13 AMF ran 96 critical tests on a total of 29 core loadings with a simulated PTR core in the reactor pool at Industrial Reactor Laboratory, Plainsboro, N. J. Minimum critical mass (3.25 kg U^{235}) came out close to that calculated (3.20). Even more pleasant was the discovery that omitting one fuel element from the core center (but, of course, adding several to the perimeter) gave a thermal-neutron flux-trap peak equivalent to $>10^{15}$ n/cm²/sec at 25 Mw—or triple the top flux in a uniform core.

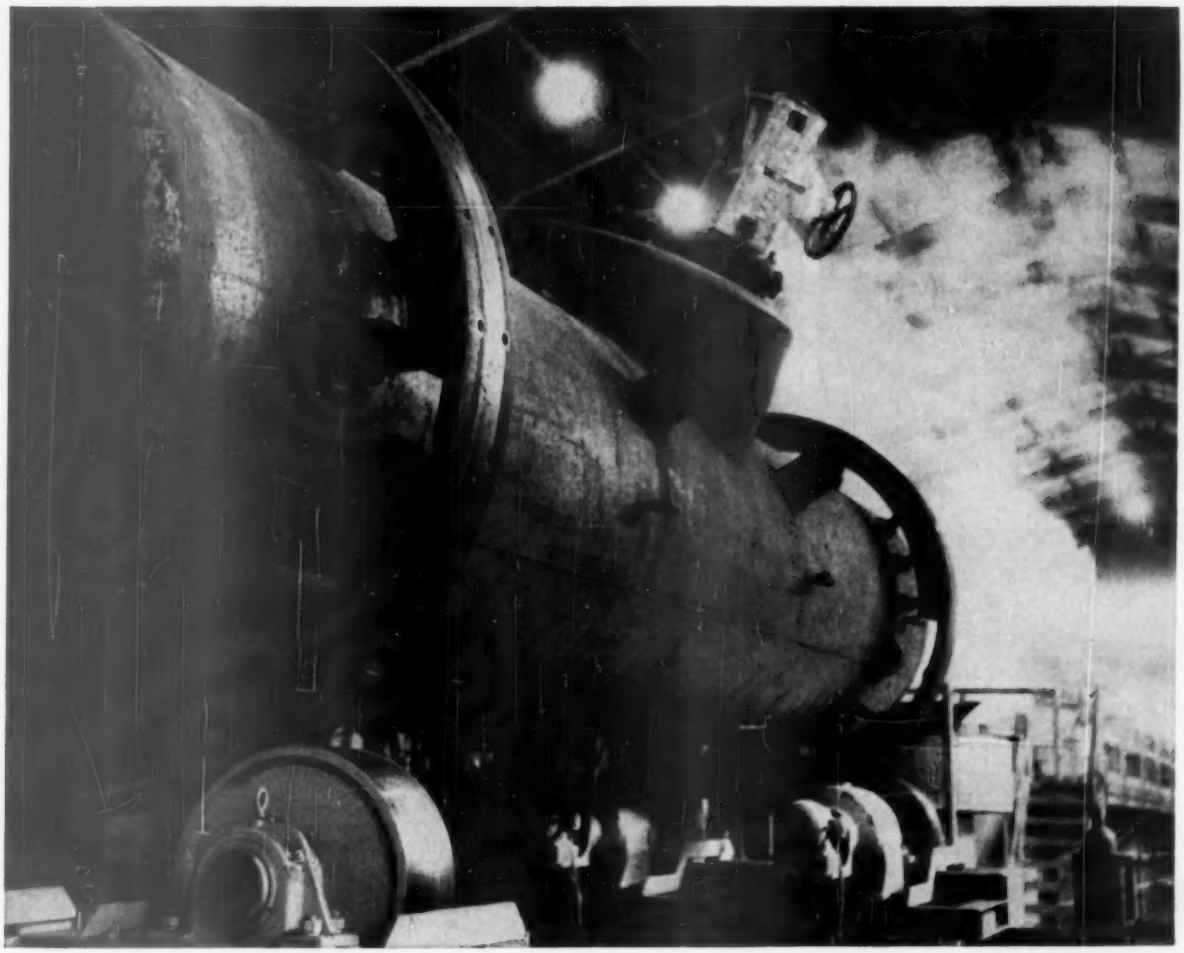
Flow tests. In its loop at Greenwich, Conn., AMF has tested a PTR fuel element in water flowing at 250 gpm (flow at 25 Mw would be 270 gpm) to measure over-all pressure drop and flow stability. These tests led to decisions to (a) use the fourth fuel tube (instead of the fifth) as the barrier between the two coolant passes so as to reduce the pressure difference across the barrier, (b) pass coolant up the outer annulus and down the inner one so the higher pressure in the first pass will push the barrier fuel tube-plate tighter into its web slot rather then tending to loosen it and (c) weld the three fuel-element webs to the pressure tube at the top and bottom rather than fastening them at just one end.

Flow tests now are checking the effects on fuel elements of flow cycling (repeated quick starts and stops) and a 500-hr endurance run is being considered. In coming months these tests will be repeated with flow rates up to 400 gpm—which will define whether the present design can go up to 40 Mw.

Other tests have verified the effectiveness of the simple contact seal between the grid and pressure tube when the water is clean. New tests are checking effects of dirt in the seal.

Fuel configuration. As in the Sylcor-fabricated fuel elements for the tank-type Belgian test reactor BR-2, each PTR fuel element consists of six concentric fueled "tubes." Each uranium-aluminum fuel tube is made up of three 120-deg curved plates whose side edges are roll-swaged into slots in three aluminum support webs that extend the 25-in. length of the plates. In PTR the pressure tube fastens around the fuel-tube assembly and a cap atop the pressure tube reverses the coolant flow so the water goes through the fuel element in two passes.

Fuel programming. With a hexagonal core load of 24 fuel elements (each containing ~220 gm U^{235} and 1.4 gm natural boron as burnable poison) and five double-Y-shaped control rods about 9% reactivity excess will be available for burnup. This gives an average fuel-element life of 45 days (about the same as that of the fuel in the Oak Ridge Research Reactor); in this way the PTR will use 165 fuel elements during an operating year of 300 days at 25 Mw. To maintain reactivity as operation proceeds the operator periodically will add beryllium reflector elements to the core periphery and will replace groups of spent fuel elements.



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Search for a Nuclear Thermionic Emitter

by PAUL STEPHAS, *General Electric Company, Pleasanton, California*

One of the important problems of developing a thermionic device to convert nuclear heat into electrical energy is finding a suitable thermionic-emitter material to coat the nuclear fuel. For a converter using ionized gas (such as cesium) the emitter material should have

- high melting temperature—at least 2,000°C
- noncondensable vapor pressure no higher than 10^{-2} mm Hg at the operating temperature
- evaporation rate low enough to permit long operational life
- large thermionic current density
- either low neutron cross section or the capability to be used as very thin coatings.

A survey of the literature turns up well over a hundred elements and binary compounds with melting temperatures over 2,000°C. (See for example Refs. *1* and *2*. Note also the large disparity between the melting temperatures obtained from different sources.) The second and third criteria listed above narrow this field down to the materials shown in Table 1.

Of this list of most promising materials, the ones that come closest to satisfying all criteria are the carbides and borides of the rare earth and transition metals. A systematic investigation of the di-, tetra-, and dodecarborides would provide a better understanding of the thermionic properties of materials, and open the possibility later of tailoring materials to obtain any desired thermionic property.

Emitter Criteria

A thermionic converter that uses a uranium-carbide–zirconium-carbide solid solution as *both* emitter and heat source has been built and operated in a reactor with moderate success (*3*, *4*).

This combined fuel-emitter approach fixes the thermionic characteristics of the device and may present other problems. For example Battelle reports that fission products recoil from the uranium carbide and collect in the space around the fuel (*5*). These fission products might contaminate the low-pressure cesium vapor in a converter. A solution to this is to have a nonfissile emitter coating the fuel to a thickness greater than the recoil distance, perhaps with a diffusion barrier between them.

Operating temperature. The maximum temperature at which the emitting material can operate in a reactor is determined by the maximum temperature of the nuclear fuel. The fuel will ordinarily not be molten because of the associated fuel-containment problems. Indeed the surface temperature of the fuel will probably be low enough to enable the fuel to support its own weight. For example although uranium carbide melts at about 2,500°C, it can be easily deformed by plastic flow at 1,800°C (*6*). The melting points of high-temperature uranium binary compounds range from 2,400 to 2,850°C for the carbides UC and UC_2, uranium nitride and uranium dioxide. Higher melting points are possible with ternary alloys; an alloy of uranium carbide (UC) with 25 m/o (mole per cent) of zirconium carbide as a solid solution melts at 3,000°C. If we consider the thermal conductivity of the fuel, the need for the fuel to support its own weight, and the emission cooling of the surface at large power output for the thermionic converter, the surface temperature of the nuclear fuel and, hence, the emitter temperature will probably not exceed 2,500°C.

To establish a lower temperature limit we note that for anodes presently available a converter efficiency greater than 20% and an electric-power output greater than 20 watts/cm² of emitter surface would require an emitter temperature greater than 2,200°C (*7*, *8*). Therefore we are interested in seeking possible emitters among those materials that melt above 2,000°C.

Evaporation rates. An important limitation on the life of an emitter is its rate of evaporation. This rate is highly temperature dependent and usually becomes quite large near the

(*Continued on page 70*)

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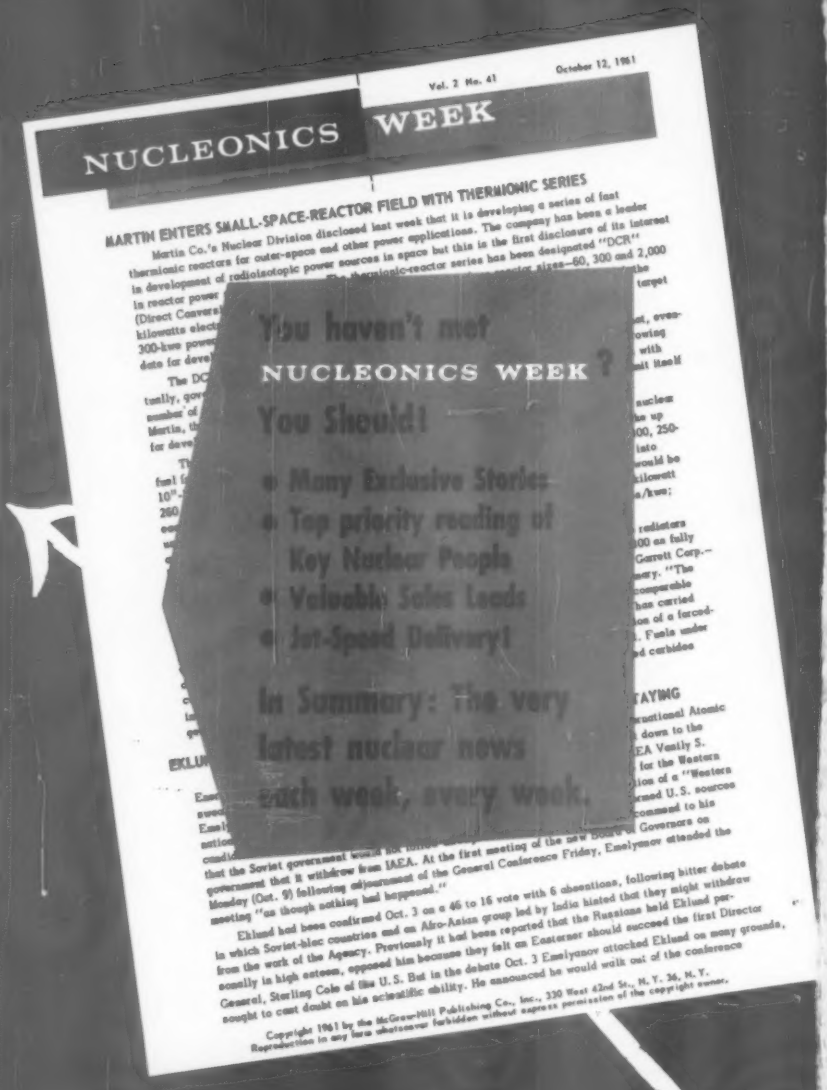
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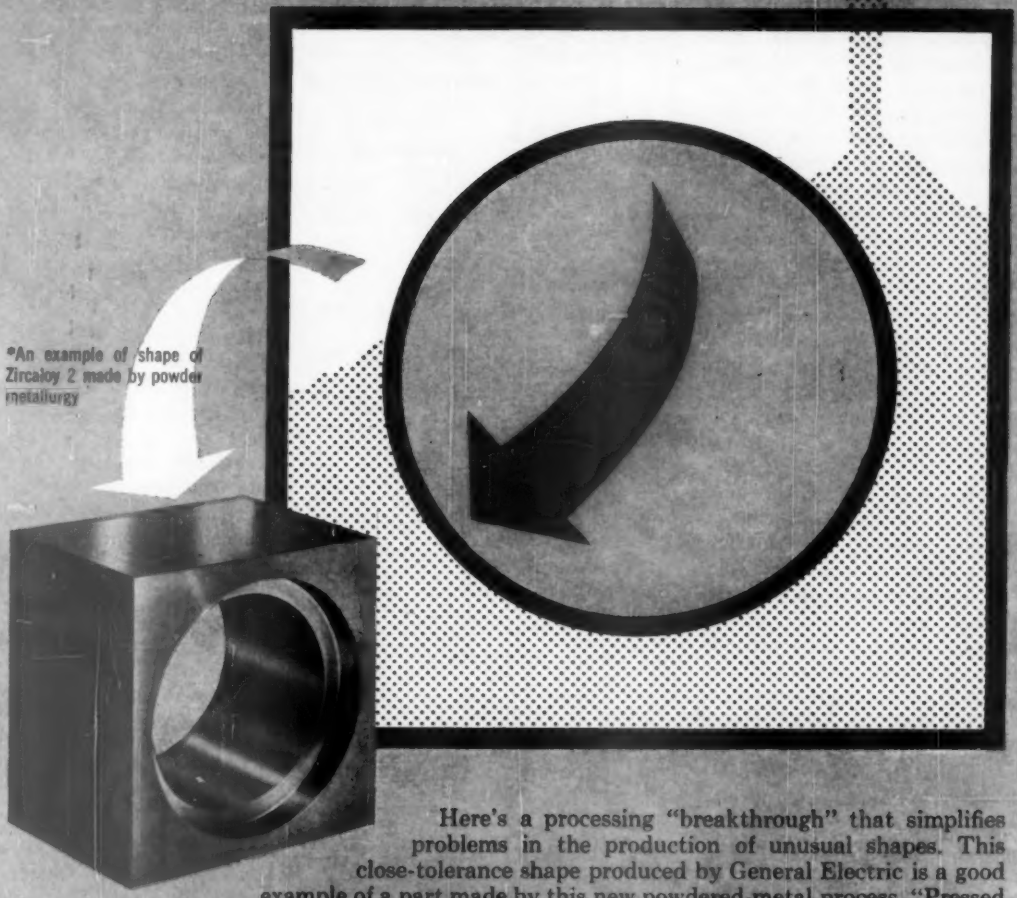

*An example of shape of Zircaloy 2 made by powder metallurgy

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melting point of the material. If the evaporation rate is significant at the operating temperature, the material may deposit on the surfaces of the insulators or close the cathode-to-anode gap by uneven deposition on the cold anode; either will tend to short out the device and make it inefficient or inoperative.

Many oxides, nitrides, and sulfides evaporate by dissociation, forming noncondensable gaseous species. The electron scattering due to such gases will be tolerably low if the noncondensable vapor pressure of the emitters is at least one tenth the vapor pressure of the cesium gas. The cesium vapor pressure of an operating device will probably be no lower than 0.1 mm Hg. Thus, the maximum noncondensable vapor pressure of suitable emitters must not exceed 10^{-2} mm Hg at the operating temperature.

Table 1 lists several compounds that melt above 2,000°C and probably have evaporation rates in this range.

Oxides in general have high vapor pressures above 2,000°C (*1, 9*). In particular CaO, Cr_2O_3, MgO, SrO, UO_2, ZrO_2 and probably HfO_2 cannot be used in a vacuum at these temperatures. The rare-earth oxides probably also have high vapor pressures, but may be suitable at lower temperatures (*10*). This leaves thorium dioxide (ThO_2) and beryllium oxide (BeO) as possible candidates, although the latter may have high electrical resistivity.

The nitrides usually dissociate at or just above their melting points, while some dissociate considerably below (*11*). Titanium and zirconium nitrides, and the graphitic form of boron nitride all melt near 3,000°C. At 1,700°C their thermionic current density is reported to be about 0.04 amp/cm² (*12*); the investigators, however, could not measure the work functions due to the very high vapor pressures of these materials. The mono-nitrides of hafnium, thorium and uranium have dissociation pressures greater than 10^{-2} mm Hg at 2,300°C (*11*). Similar results can be expected with the nitrides of other metals.

Brewer and his colleagues report the vapor pressure of thorium monosulfide (ThS) to be around 10^{-3} mm Hg at 2,200°C, while the other thorium sulfides, uranium sulfide (US), cesium sulfide (CeS), and barium sulfide (BaS) are quite volatile at this temperature (*11*). All the rare earth and transition-metal sulfides are probably volatile at this temperature.

Lafferty reports that the evaporation rate of the rare-earth hexaborides was low enough to allow him to measure the work function of some of these materials (*13*). In Russia, rare-earth hexaborides have been used as thermionic emitters in a synchrophasatron, magnetron accelerator, and a cyclotron with lives up to 250 hr, compared with 12 hr for tantalum cathodes (*10*). Other borides are equally stable.

The refractory carbides are generally quite stable in vacuum at 2,200°C; NbC, HfC, MoC, TaC, Ta_2C, ThC_2, TiC, WC, W_2C, and ZrC have vapor pressures below 10^{-4} mm Hg (*11*). At 2,100°C, the vapor pressure of SiC is about 10^{-2} mm Hg (*14*) and that of Al_4C_3 is about 0.5 mm Hg at 1,800°C (*15*). Thus, not all high-melting carbides are suitable as high-temperature vacuum materials.

Graphite has a vapor pressure of about 10^{-4} mm Hg at 2,100°C (*16*). Diamond and borazon* are thermodynamically unstable at low pressures. Diamond completely transforms to graphite at 2,000°C (*17*) with the transformation starting at about 1,300°C.

Finally the monocarbides of the rare-earth metals probably exist, have high melting points, and low evaporation rates.

TABLE 1—Low-Vapor-Pressure Materials Melting Above 2,000°C

	Compound melting point (°C)			
Element	*Boron compounds*		*Carbon compounds*	
Ba	BaB_6	>2,000		
C	B_4C	2,450	Graphite	4,000
Ca	CaB_6	2,300		
Ce	CeB_6	2,190	CeC_2	>2,300
Dy	DyB_6	?		
Er	ErB_6	?	ErC_2	>1,900
Eu	EuB_6	2,500		
Gd	GdB_6	>2,150	GdC_2	>2,200
Hf	HfB_2	3,250	HfC	3,900
			HfC-2TaC	4,140
Ho			HoC_2	>1,900
La	LaB_6	2,200	LaC_2	>2,000
Mo			Mo_2C	2,700
			MoC	2,700
Nb	NbB	2,300	NbC	3,400
	Nb_2B_4	2,700		
	NbB_2	3,050		
Nd	NdB_6	2,540	NdC_2	>2,000
Pr	PrB_6	?	PrC_2	>2,200
Sc	ScB_6	?	ScC	>1,900
Sm	SmB_6	2,400	SmC_2	>2,200
Sr	SrB_6	>2,000		
Ta	TaB	2,400	Ta_2C	3,400
	Ta_2B_4	2,600	TaC	3,900
	TaB_2	3,100		
Tb			TbC_2	>1,900
Th	ThB_4	>2,500	ThC	2,600
			ThC_2	2,600
Ti	TiB_2	2,700	TiC	3,200
U			UC	2,400
			UC_2	2,450
V	VB	2,200	VC	2,800
	V_2B_4	2,300		
	VB_2	2,400		
W	W_2B_5	2,300	W_2C	2,700
	WB	2,400	WC	2,600
Y	YB_2	2,100	YC_2	>2,300
	YB_4	2,800		
	YB_6	2,600		
	YB_{12}	2,200		
Yb	YbB_6	>2,000	YbC_2	>1,900
Zr	ZrB_2	3,000	ZrC	3,500
	ZrB_{12}	2,600	ZrC-4TaC	3,900
	Other Compounds			
	BeO	2,600	SiC	2,850
	ThO_2	3,050	Re_2W_2†	3,000
	ThS	>2,200		

† Existence has been questioned.

Thermionic emission. The thermionic current density J for a given material can be described by the Richardson-Dushman equation:

$$J = AT^2e^{-\frac{e\phi}{kT}}$$

ϕ is the thermionic work function of the emitter

T is the absolute temperature of the emitter

k is Boltzmann's constant

e is the electronic charge

The emission constant A has a theoretical value of 120 amp/cm²-°k^2 for clean metal surfaces. Both the work function and the emission constant may be functions of the temperature (*18, 19*). In this situation a Richardson-Dushman type equation will usually still describe the data, but ϕ and A are now the Richardson work function and the Richardson emission constant obtained from the slope and intercept of a plot of log J/T^2 against $1/T$. Alternatively, the theoretical value of the emission constant can be used to calculate an effective work function for a given temperature. The latter method may give more consistent results in thermionic-converter calculations. (*Continued*)

*Boron nitride with a diamond structure.

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Table 2 lists the Richardson work functions and emission constants for several high-temperature materials. We see from the data that the work functions quoted by various investigators might differ by 30% and the emission constants by orders of magnitude (see for example the data for UC and ZrC). Aside from sample and surface impurities, such discrepancies are usually attributed to the crystal orientation of the surface grains, their relative sizes, and the magnitude of the accelerating potentials used to obtain the data (*18*). These factors join to form a "patch" effect, which is exaggerated when the emitter is a semiconducting material.

The work function and emission constant obtained with a weak accelerating field are more directly applicable to thermionic-converter calculations, because these devices operate in the weak-field region. One must exercise caution in using such data because they refer to a specific range of grain sizes and orientations. The magnitudes of the weak-field coefficients are larger than those obtained with a strong accelerating field.

One method of ionizing cesium vapor is to allow it to come in contact with a hot surface whose work function is greater than 3.87 volts, the ionization potential of cesium. A piece of hot tungsten can be introduced into the cell for this purpose (*20*). The Los Alamos device may use the uranium-carbide–zirconium-carbide emitter for the ionization surface (*3*). The hexaborides of neodymium, samarium, europium and possibly promethium and terbium as well as ZrB could be used similarly as ionization surfaces as well as emitters.

Neutron cross-section. Since we are concerned with thermionic converters for use in a nuclear reactor, the neutron cross section of the emitter material is important. A very low cross section is not necessarily required because only a thin surface layer of emitting material is needed. The thickness of this layer is determined by the evaporation rate of the material and the length of operating time desired.

Borides are not disqualified if the small-cross-section isotope B^{11} is used, or if thin layers are used. Similarly not all the rare earths have such large cross sections as to be useless.

Emitter Materials

The five dozen or more possible emitter materials listed in Table 1 are the result of applying the previous criteria. It would require a heroic effort to fabricate each of these and measure its thermionic properties in a reasonable length of time. The fifteen that melt above 3,000°C, however, should be investigated for devices designed to operate at 2,500°C. In this group are carbides and borides of transition metals that have large Richardson-emission constants in conjunction with large Richardson work functions.

At present, we cannot predict the exact thermionic behavior of materials but work is progressing in this direction. Samsonov and Neshpor (*21, 22*) have correlated the work functions of the rare-earth hexaborides with the atomic number of the metals and find a fairly smooth dependence. They further correlated this dependence to the number of possible states of the 4*f* electrons. Kmetko (*23*) suggests that

TABLE 2—Thermionic Properties of Promising Materials

	Work function ϕ (*v*)	*Thermionic constant* A (*amp/cm²-°K²*)	*Emissivity**	*Reference*
W	4.45	38	0.43	*18*
W	4.55	75		*18*
Ta	4.19	55	0.49	*18*
Ta	4.10	37		*18*
Mo	4.20	55	0.37	*18*
Mo	4.33	25		*18*
Nb	4.01	37	0.37	*18*
ThO_2	2.55	3.3	0.40†	*12*
TiC	2.35–3.35	25	0.96	*12*
ZrC	2.18	0.31	0.96	*12*
ZrC	3.8	134	0.7	*24*
ZrC-20 m/o UC	4.3	6.6×10^4	0.8	*24*
UC	4.57	7.3×10^5	0.9	*24*
UC	2.94	33	0.9	*25*
TaC	3.14	0.30	0.67	*12*
ThC_2	3.5	550	0.8	*12*
TaB	2.89	10	0.70	*12*
ZrB	4.48	3.5×10^4	0.70	*12*
BaB_6	3.45	16		*13*
YB_6	2.2	15	0.7	*26*
LaB_6	2.66	29		*13*
LaB_6	2.68	73	0.7	*26*
CeB_6	2.59	3.6		*13*
CeB_6	2.93	580	0.68	*26*
PrB_6	3.46	300	0.67	*26*
NdB_6	3.97	420	0.64	*26*
SmB_6	4.4		0.68	*22*
EuB_6	4.9	$1–5 \times 10^3$		*22*
GdB_6	2.05	0.84	0.65	*26*
DyB_6	3.53	25.1	0.7	*26*
HoB_6	3.42	13.9	0.7	*26*
ErB_6	3.37	9.9	0.7	*26*
YbB_6	3.13	2.5	0.7	*26*
LuB_6	3.0	0.36	0.7	*26*
Misch-metal B_6	2.64	14		*13*
CaB_6	2.86	2.6		*13*
SrB_6	2.67	0.14		*13*
ThB_6	2.92	0.5		*13*
ScB_6	2.96	4.6	0.6	*22*
LaB_{12}	2.16			*22*
CeB_{12}	2.20–2.24			*22*

* Emissivity at 0.65μ. † Increases to 1.0 above 1,600°C.

the anomalously large and small emission constants A arise because the carbon or boron atoms increase the distance between the metal atoms enough to cause the incomplete f or d subshells to form narrow nondegenerate energy bands. Additional data on the di-, tetra-, and dodecarborides should help clarify thermionic behavior and possibly reveal some very useful emitters.

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Radionuclide Tags Simplify Bird-Migration Studies

How can one follow the complicated pattern of bird migrations quickly and simply? Tag them with radionuclides, say biologists at Hanford Laboratories, who explain that the nuclear age has now entered the bird-banding business in the state of Washington. No longer must birds in the Hanford area suffer the trials and tribulations of being handled and tagged with tiny metal bands that help ecologists trace their migration. Instead by simply feeding in the Columbia River that flows through and cools the eight Hanford plutonium reactors game birds are automatically tagged with tiny amounts of radionuclides that are harmless to them but will give biologists later on a sure indication that the birds were in the neighborhood. Not only is this method far simpler and quicker than the conventional bird-banding technique—first you catch the bird, then fit it with the metal tag—but also it should lead to far greater knowledge of bird migratory habits in the northwestern part of this country.

The system works like this. As the river flows through the Hanford reactors slight amounts of P^{32} (14.5-day half-life) and Zn^{65} (245-day half-life) form and are carried out of the reactor. When the birds feed in the river they absorb small amounts of these nuclides —the average total beta radiation including fallout from all birds tested is 0.2 nanocuries/gm wet weight (nano = 10^{-9}); the amount varies depending on the feeding habits of the birds and the length of time they stay at the river. The Hanford Laboratories then gather from sportsmen and wildlife organizations the heads of fowl that have been killed and analyze them with a multichannel gamma analyzer and a low-background beta counter.

So far the laboratory has gathered and studied more than 600 heads from game birds tagged with radionuclides from the river. These heads represent 14 varieties of waterfowl including ducks, geese and mergansers. About 41% of all the birds sampled at Hanford stayed in the Columbia-River region long enough to be labeled. The time required varies from two days to two weeks depending on the species of bird. Hanford ecologists report that nearly all the 300,000 water fowl that winter in the 600-square-mile nuclear reservation are currently tagged by trace amounts of nuclides.

Hanford findings on bird migrations indicate that the birds in the region generally fall into two categories: those in the upper Hanford area are stable and remain for relatively long periods of time. Birds in the lower region on the other hand are transients. They feed for a short time and then migrate over a large area of southeastern Washington. Moreover Hanford biologists have found that there are different seasonal peaks of tagged birds in regions surrounding the Hanford reservation. During the 1960–1961 waterfowl season the largest influx of migrants to all areas came during the last week in November when a smaller proportion of Hanford-labeled birds showed up in the neighborhood.

Neutron-Activation Analysis: New Tool Against Crime

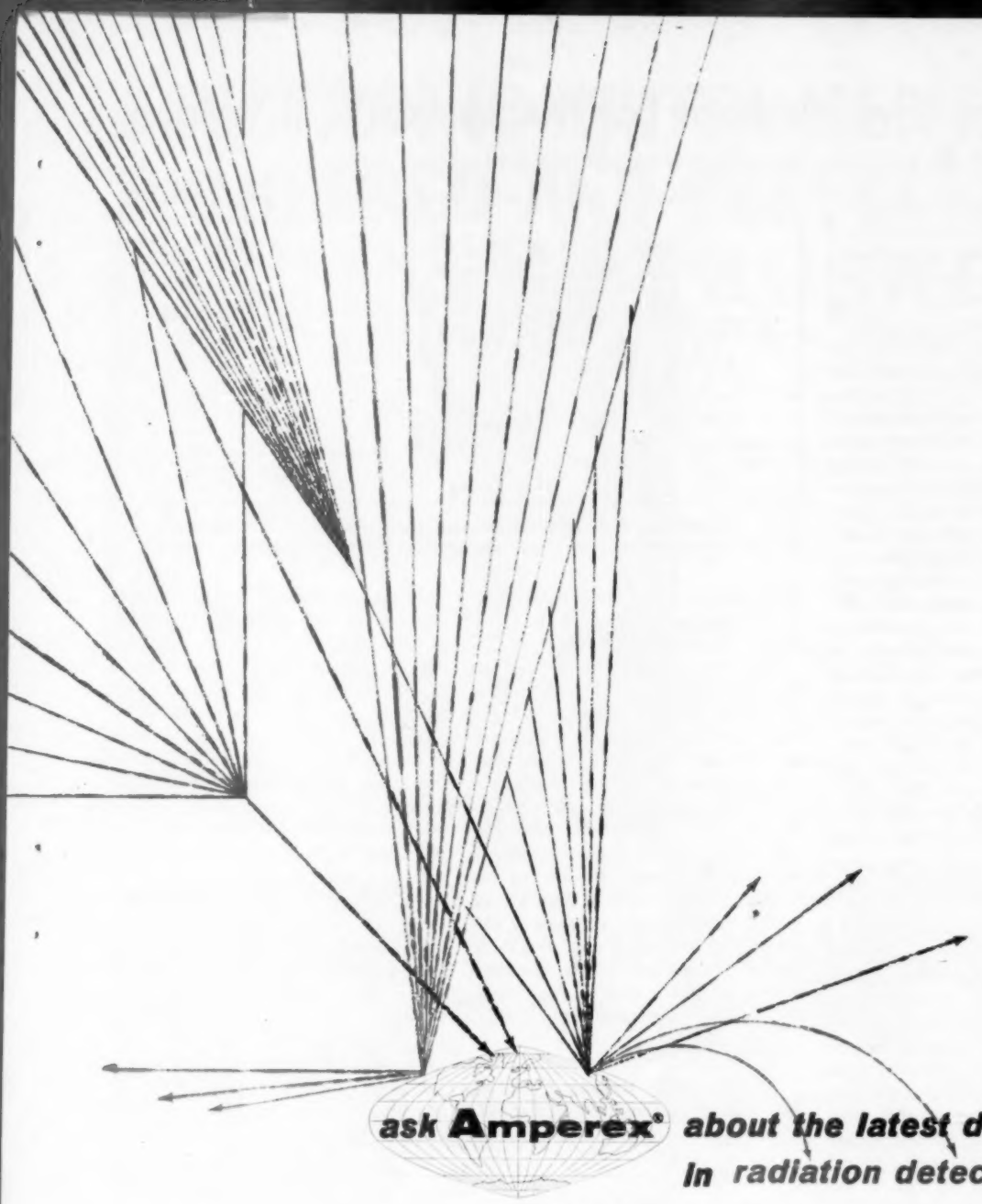
The newest detective in the world of criminology is neutron-activation analysis. By using this extremely sensitive and accurate technique criminalists think that they may often be able to blast a suspect's alibi wide open. For example neutron-activation analysis can tell you whether a suspect recently fired a gun; it can identify a tiny piece of hair caught in a victim's fingernail and match it with the hair of a suspect; it will analyze and match blood samples with great precision and even identify a fleck of paint on an automobile bumper —often too small to be analyzed by the most sensitive spectroscope—as coming from a particular car during a collision; and perhaps in the future it will examine a sliver of glass found in a suspect's trouser cuff and show that it came from a broken window at the scene of a robbery.

In California, General Atomic and the Los Angeles Police Department have been working hand in hand to find out how activation analysis can best be used in criminology. So far, according to Robert M. Watkins, a radiochemist at General Atomic, the results have been very good—especially for proving that a suspect recently fired a gun by finding minute powder stains on his hand. Although other techniques have been tried in the past to identify gunpowder residues, none has so far been practical. Now activation analysis allows investigators to detect traces of residue as small as 2.5×10^{-11} gm left on the hand of the person firing a gun.

How do police criminalists use neutron-activation analysis? First they wash the hand of the suspect with a special solvent. This solution is put in a capsule, irradiated for 30 min in the General Atomics TRIGA Mark I reactor at a flux of 1.8×10^{12} n/cm²/sec and then analyzed. To improve the limits of detection in their early work, criminalists have used simple radiochemical separations.

For analyzing blood stains neutron-activation analysis also promises to be far more effective than conventional chemical tests. Moreover activation analysis results from hair studies have already been admitted as evidence in French and Canadian courts.

Three outstanding advantages stand out for applying neutron-activation analysis to criminology. First because the method is extremely sensitive it can identify and measure parts per million —or in some cases even parts per billion. Second it can analyze very tiny samples of evidence left at the scene of a crime or carried away by the criminal and later recovered by the police. And third, since the method is nondestructive, a specimen after analysis can be taken into the court room in its original undamaged form to be used as evidence. Consequently although the application of activation analysis to criminology is still in its infancy, the technique holds great promise for the future.



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Comparing Two Methods For Measuring Tool Wear

by SLAVCHO POPOV, *Research Institute on Machine Building and Metal Working, Sofia, Bulgaria*

To measure wear and tear of separate cutting surfaces on a cutting tool, engineers in Bulgaria and the Soviet Union are using two new techniques—the Nadeinskaya and the Colding methods—each of which measures radiation from W^{187} tracers. Because they determine wear on both the front and rear tool cutting surfaces, these two methods overcome the disadvantages of other tracer techniques that measure only the total wear from all cutting surfaces. At the All-Union Research Institute in Moscow we studied these two methods to find out what the advantages and defects of each are.

Our results show that although both methods give similar results, the Nadeinskaya technique is more precise than the Colding one—particularly at greater cutting speeds. The Colding method, on the other hand, is simpler and more rapid and represents an express technique for measuring wear. Both methods, however, measure cutting-surface wear several times more rapidly than existing geometrical or weight-measuring methods that do not use radionuclides.

Nadeinskaya Method

In the Nadeinskaya technique we use two tools to cut a surface—one tool contains W^{187} and the other is nonradioactive. As Fig. 1 shows, when they cut material, tools wear away on their front and rear surfaces. Particles containing tracers from the *front* surface of the radioactive tool stick only to the surfaces of shavings (Surface C) cut off by this tool. Radioactive particles from the rear tool surface, on the other hand, stick to the surface of the material being cut (Surface S). Since the nonradioactive tool cuts shavings from this surface, these shavings contain tracers only from the *rear* surface of the radioactive tool.

We gathered the shavings from each of the tools separately and measured their gamma radiation with a G-M counter. These measurements gave us the total relative wear (ΔB) from the tool. Relative wear is the ratio of the material in milligrams worn from the tool to the amount of shavings in grams removed during cutting. ΔB is the sum of the relative wear from the front (ΔB_f) and from the rear (ΔB_r) surfaces. We measured ΔB_f and ΔB_r using five cutting speeds: 100, 150, 200, 250 and 300 mm/min. The other parameters such as feeding, depth of cut and processed material remain constant.

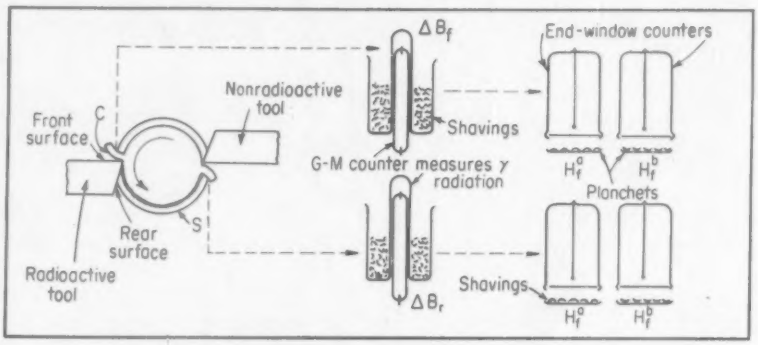

FIG. 1. NADEINSKAYA METHOD uses two tools to measure wear rates—one radioactive and one nonradioactive. Three-stage procedure gives relative wear from surfaces

After we thoroughly mixed each of the measured groups of shavings, we took three samples weighing ~1 gm from each group. We then arranged the shavings from the front and rear tool surfaces in different planchets—first laying them on one side and then on the other (Fig. 1)—and measured their beta-radiation intensity with an end-window counter. By dividing this intensity by the weight of the shavings in the planchets, we determined the specific activity of a unit weight of shavings (cpm/gm). This quantity indicates relative wear of the cutting tool (see Table; symbols are in box).

Colding Method

A single tool containing W^{187} does the cutting in the Colding method. Consequently shavings that are cut off are covered with radioactive particles on both sides; as Fig. 2 shows, particles from the *front* tool surface stick to Surface A of the shavings and particles from the *rear* tool surface adhere to Surface B.

We use the same equipment in this technique as in the Nadeinskaya method. After determining the relative wear (ΔP) with the gamma counter, we found the beta-radiation intensity with the end-window counter. The specific activity, as in the other method, characterizes wear along front and rear tool surfaces (see Table).

Measures of wear can be made with the Colding method if the shaving thickness is >0.3–0.4 mm. If shavings have thicknesses greater than this value the beta radiation on the lower side of the shavings is absorbed by the shavings themselves; only radiation

What the Symbols Mean

For Nadeinskaya method:

$B = \Delta B_f + \Delta B_r$	relative wear from front (ΔB_f) and rear (ΔB_r) tool surfaces
H_f^a	radiation intensity of unit weight of shavings containing products from wear on front tool surface (when shavings have side *a* toward end-window counter)
H_f^b	same as H_f^a except that side *b* of shaving is turned toward counter
H_f	total intensity of unit weight of shavings containing products from wear on front tool surface
H_r^a, H_r^b, H_r	same as above three values except that these apply to rear side of tool

For Colding method:

ΔP	relative wear from front and real tool surfaces
I_f	radiation intensity of unit weight of shavings containing products worn from front tool surface
I_r	same as above but for rear surface

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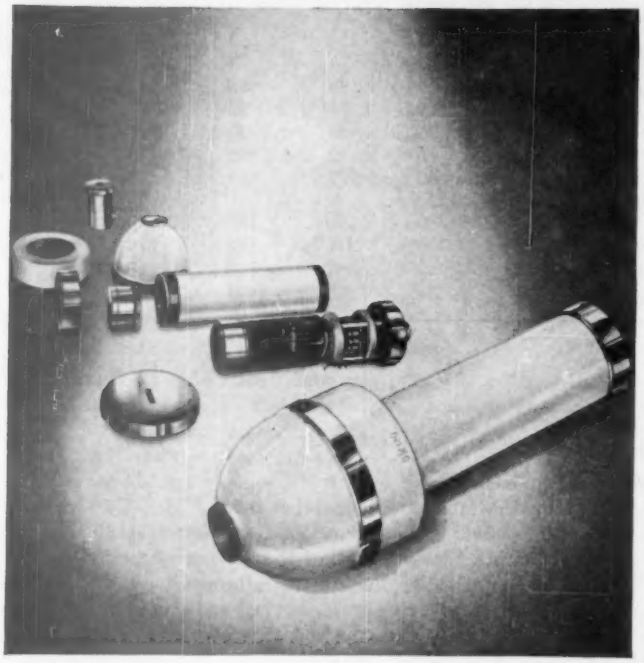

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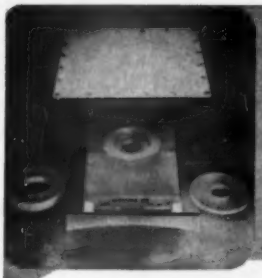

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Radiation Intensities Measured for Two Methods

Cutting speed (mm/min)	*100*	*150*	*200*	*250*	*300*
Nadeinskaya Method					
H_f^a (cpm/gm)	50	154	510	1,160	5,520
H_f^b (cpm/gm)	15	34	73	104	309
$H_f = H_f^a + H_f^b$ (cpm/gm)	65	188	613	1,264	5,830
H_r^a (cpm/gm)	16	14	22	15	14
H_r^b (cpm/gm)	25	28	20	15	27
$H_r^a + H_r^b = H_r$ (cpm/gm)	41	42	42	30	41
$H_f + H_r$ (cpm/gm)	106	277	659	289	5,866
Colding Method					
I_f (cpm/gm)	369	556	7,177	2,673	21,700
I_r (cpm/gm)	99	244	149	276	1,590
$I_f + I_r$ (cpm/gm)	468	800	866	2,949	23,290
ΔP (10^{-4}) (mg/gm)	1.35	1.01	1.23	2.60	27.2

from particles stuck to the shaving surface toward the counter registers.

Comparing the Two

To compare the two methods we used data derived from the table to plot ΔB, ΔP, $H_f + H_r$, $I_f + I_r$, H_r and I_r as functions of cutting speed (Fig. 3). In making these graphs we took advantage of the fact that ΔB and ΔP are almost equal when the cutting speed is 300 mm/min (ΔB is 0.00333 mg/gm and ΔP is 0.00272 mg/gm). Thus $\Delta B = \Delta P = H_f + H_r = I_f + I_r = 1$ for cutting speeds of 300 mm/min.

One would expect the curves for ΔB and ΔP as well as those for $I_f + I_r$ and $H_f + H_r$ to coincide in Fig. 3. They don't coincide, however, because it is impossible to create identical examination conditions. Since the character of the two sets of curves is the same, both methods give similar results.

One can also see from Fig. 3 that $H_f + H_r$ and $I_f + I_r$ have greater values than ΔB and ΔP. Two reasons account for this fact. First, a small part of the particles from the radioactive tool adhere to the surface edges of the shavings and consequently influence counter readings from both sides of the shavings. Second, in measuring with the end-window counter one records not only beta radiation from the upper side of the shavings but also a small amount of gamma radiation from both sides. This imperfection in measurement also affects the I_r curve, which increases considerably with larger cutting speeds while H_r hardly changes. If shavings have about the same activity on both sides, the gamma influence from the lower side is not great. If, however, the difference in activity from the two sides is large, when the more active side of the shaving is turned away from the counter its influence is considerable. This fact is so even though the amount of gamma radiation registered by the counter as compared with that of beta radiation is insignificant.

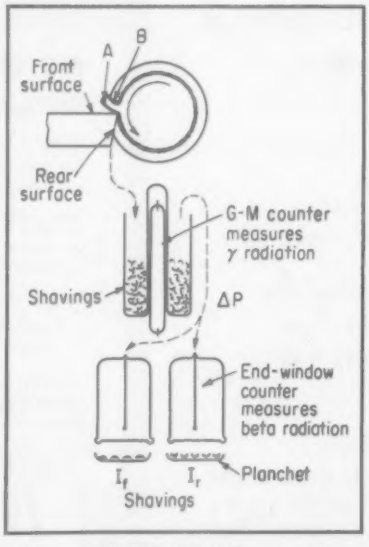

FIG. 2. COLDING METHOD uses only one tool—a radioactive one—to measure wear

Conditions for Experiments

To make sure that our experiments were correct we made checks on our equipment and methods. In our first check to find how beta radiation is absorbed, we put, one after the other, four iron plates—each 0.28 mm thick—above the planchet holding the shavings and then measured the beta radiation. After turning the shavings over on their other sides, we repeated the measurement. Our results show that

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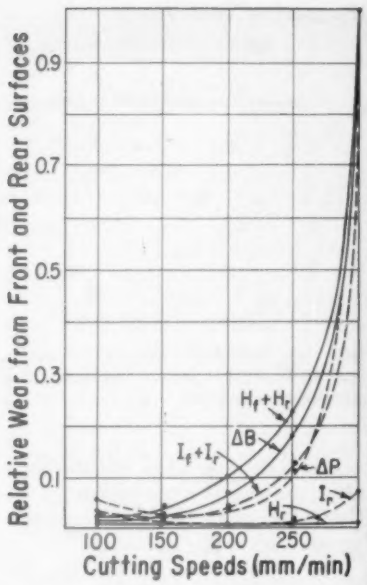


FIG. 3. RELATIVE WEAR AND CUTTING speed show methods give similar results

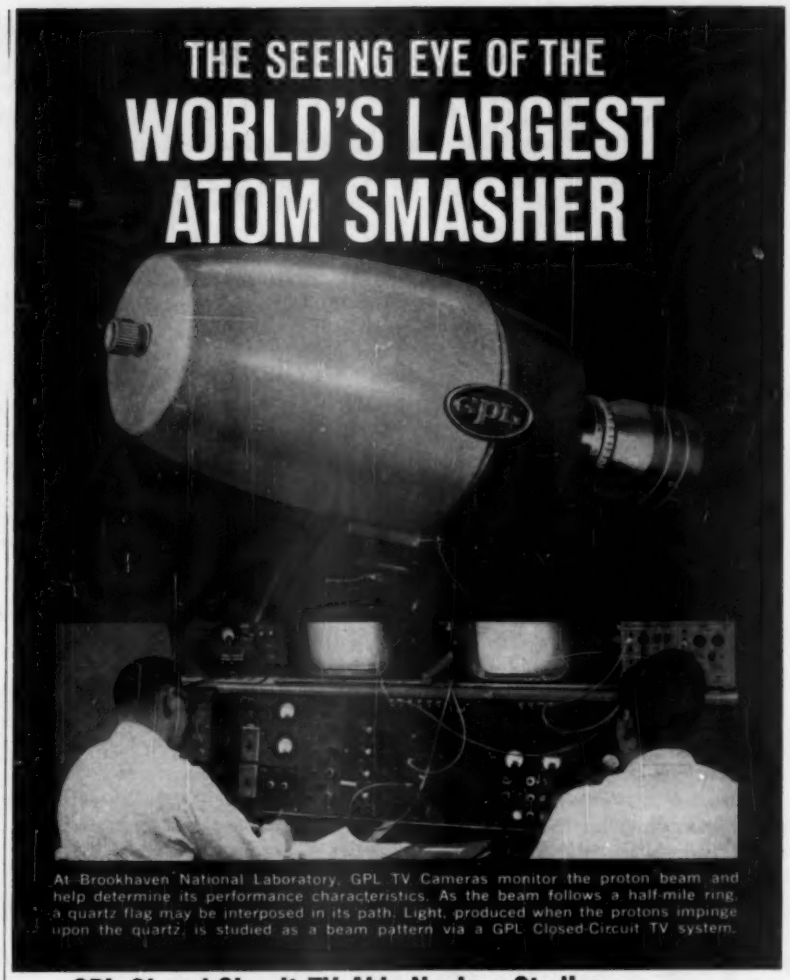
when the thickness of the absorber increases, the intensity measured decreases. In addition, besides background radiation the end-window counter registers an insignificant amount of gamma radiation that does not change with different absorber thicknesses. This fact may explain the differences in curves in Fig. 3.

One must also check to see whether the counter measurements are different if one changes the position of shavings from the same sample. To make this check we put shavings from the same sample in the planchet in different positions and took measurements. We found that deviation from the mean arithmetical value of intensity did not exceed $\pm 5\%$. Deviations in intensity from shavings obtained at the same cutting speed did not exceed $\pm 10\%$.

Finally we plotted the dependence between $(I_f + I_r)/\Delta P$ and the thickness of the shaving in Fig. 4. In making the graph we assumed that when the shaving thickness is 0.82 mm, $I_f + I_r = \Delta P = 1$. One can see that when the shaving thickness is <0.4 mm, one should not use the end-window counter because of the deviation.

What We Found

As Fig. 3 shows, the two methods give almost the same results. Nevertheless the Nadeinskaya tool-wear method gives more precise results than the Colding technique, especially at greater cutting speeds. In addition this method enables one to make in-



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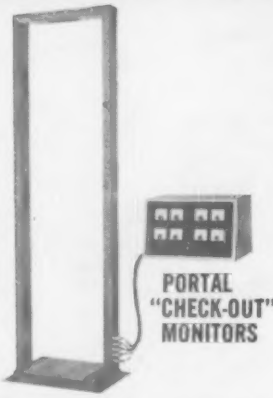

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Measuring Tool Wear

This article starts on page 76

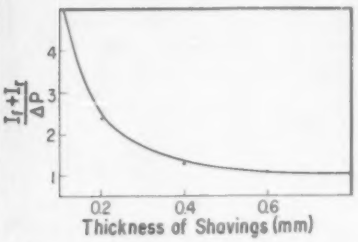

FIG. 4. SHAVING THICKNESS versus intensity shows that when thickness is <0.4 mm deviation is great

vestigations even when the thickness of the shavings is <0.3–0.4 mm; in the Colding method errors are considerable for shavings of this thickness.

The Nadeinskaya method has the disadvantage that shavings are cut by two cutting tools. This two-tool arrangement is complicated and its application—particularly on small shaving thicknesses—results in considerable time loss for adjustment.

The principal advantage of the Colding method on the other hand is that it represents a quick and simple way to measure cutting-tool wear.

With both methods, however, as compared with other existing techniques, one can determine surface wear several times more rapidly and comparatively more precisely. Thus these techniques are important for instrument- and machine-building plants.

* * *

I would like to express my thanks to Eng. Krasko, director of the Isotopes Laboratory at the All-Union Instrumental Research Institute in Moscow.

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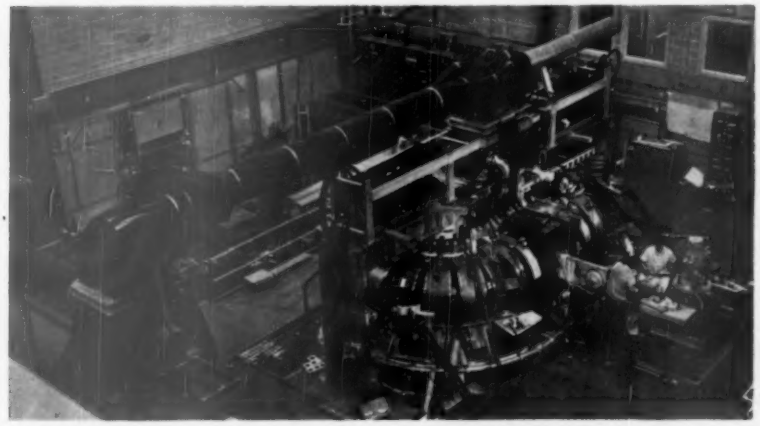
THERMONUCLEONICS

Model-C Stellarator Starts Up at Princeton

Following many years of planning and preparation the Model-C stellarator began operating on a limited basis during the past summer. With this massive instrument—the largest and most expensive of the fusion-controlling devices now being explored in the United States—physicists hope to unravel many of the mysteries of high-temperature plasmas and pave the way for their ultimate goal—controlled thermonuclear fusion.

As you will recall, the C-stellarator works in the following way. Gases in the race-track-shaped stainless-steel vacuum vessel are partially ionized by 100–250 kc pulses (1–10 msec, 400 kw peak power, 3 pulses/min at 10 msec or 10 pulses/sec at 1 msec) and confined within the 8-in. diameter vessel by a magnetic field that can reach 40 kilogauss. To completely ionize and raise the plasma temperature one uses ohmic heating—two large coupling transformers around the stellarator U-bends induce currents up to 50,000 amps in the plasma causing ions and electrons to heat up on collision. This heating method, however, breaks down at ~1,000,000°K because electrons run away with the energy and no longer collide with ions. Therefore above 1,000,000°K a form of magnetic pumping is proposed. By alternately increasing and decreasing the confining magnetic field, at a resonant frequency one can couple energy into the plasma. With this heating the Princeton plasma physicists hope to bring the plasma up to 100,000,000°K—a useful temperature for fusion.



C-STELLARATOR, now operating on limited basis, still needs divertor and magnetic-pumping equipment before it can reach temperatures and confinement needed for fusion

To minimize loss of energy through radiation—the "pump-out" problem—impurities in the C-stellarator must be kept low. Therefore the C-stellarator will have an elaborate vacuum system as well as a divertor that magnetically scrapes off impurities in the outside of the plasma.

Although an enormous amount of hardware has now been assembled at the Princeton Plasma Physics Laboratory for this project, the Model-C stellarator is still quite a way from completion. So far the stellarator has been operating without the stabilizing winding, divertor and magnetic-pumping equipment.

In the meantime operation of the parts already in place is being checked out. In particular the ohmic-heating and vacuum system are being tested. So far the vacuum system has worked to pressures as low as 10^{-8} mm Hg, although normal operating pressures are 10^{-4} mm Hg. In addition Princeton physicists are checking the pump-out phenomenon and the relation between the confinement time and radius of the vessel. Although results are still preliminary, Donald Grove, in charge of the C-stellarator, announced at the September IAEA controlled-fusion conference in Salzburg that despite observations of the pump-out phenomenon, the confinement time is more than an order of magnitude longer than that for the B-3 stellarator. By comparing in detail results from models B-3 and C, the Princeton group finds that the confinement time is proportional to the square of the plasma radius, thus confirming the idea that plasma is lost by a diffusion process.

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Modern Physics for the Engineer

Edited by LOUIS N. RIDENOUR and WILLIAM A. NIERENBERG (McGraw-Hill Book Co., New York, 1961, $9.50, xv + 384 pages)

Practical Nucleonics

By F. J. PEARSON and R. R. OSBORNE (E. & F. N. Spon Ltd., London, 1961, $4.50, xvi + 208 pages)

Introduction to Nuclear Science

By ALVIN GLASSNER (D. Van Nostrand Co., Inc., Princeton, N. J., 1961, $3.75, x + 213 pages)

Reviewed by JOHN D. RANDALL, Department of Nuclear Engineering, Agricultural and Mechanical College of Texas, College Station, Texas

None of today's engineers would question the importance of keeping abreast of current developments in modern physics. Too few, however, probably keep informed of progress in fields other than their own. The second edition of "Modern Physics for the Engineer" will help relieve this problem and I highly recommend it to every engineer.

The rewards from reading this book are many fold. First, it accomplishes its objective of covering the work in physics today. The topics include work in high-energy physics, nuclear structure, solid state, superconductivity, magnetohydrodynamics, origin of the nuclear species, radio astronomy, origin of the earth's magnetic field, fusion, reactor technology and hypersonic research.

Second, it points out that the separation between various disciplines is vanishing. Some direct evidence in support of this statement is the combination of hydrodynamics, electricity and magnetism, and nuclear physics necessary in fusion research or the inclusion of molecular and ionic physics in hypersonic aerodynamics. Perhaps the most significant benefit from the book is pure enjoyment. Each of the sections of the book is written by one of the most eminent men in his field. In every chapter one can feel and share the enthusiasm of the author as he discusses current problems under investigation.

The reader who picks up this book will find it difficult to lay down until he has read it from cover to cover. It is refreshing to find a book on modern physics that displays the field as the exciting and stimulating science it really is.

The authors describe the second of these three books, "Practical Nucleonics," as a course of experiments in nuclear physics and nuclear engineering. In the early part of the book they introduce important fundamental concepts such as the quantum hypothesis, which is examined in an experiment on hot-body radiations. Then follow descriptions of the various kinds of radioactivity first using a leaf electroscope and then using a G-M counter. The coverage is completed with experiments on scintillation counting, neutron detection and "nuclear" electronics.

Although the experiments are occasionally ingenious, the book does not satisfy the need for covering experimental nuclear engineering. Entirely too much emphasis is placed on limited or outmoded techniques while important methods in wide use today are given only slight recognition.

Many of the experiments, though well organized, become little more than recipes. For example the authors outline certain procedures without explaining why they adopt them. This techniques is not conducive to the best laboratory training in which as much can often be learned by examining the design of an experiment as from the results.

One major complaint I have is that some of the descriptions and theories of experiments are simplified to such an extent that they will undoubtedly cause confusion and misunderstanding among untrained readers. For example in measuring the diffusion length of thermal neutrons in paraffin the authors give a solution to the one-group diffusion equation for a point source of thermal neutrons in an infinite medium and point out that by comparing the derived thermal-flux distribution with that determined experimentally, one gets the diffusion length. However, since the source used in the experiment is a fast one, both the theory and the experimental techniques described by the authors are invalid.

In contrast to such shortcomings, the authors stress the importance of understanding the statistical phenomena associated with all counting experiments. Basic statistics applied to radioactive decay and counting will be very beneficial to the reader.

In conclusion, I feel that although this book is not a necessary part of a nuclear engineer's library, it is sufficiently interesting and informative to be a nice "luxury."

"Introduction to Nuclear Science" is an outgrowth of a short course taught at the Argonne National Laboratory to bring high-school teachers up to date in nuclear science. The first six chapters cover nuclear particles, nuclear structure, radioactivity, nuclear reactions and radiation detection. Since even at the introductory level fundamental material must be understood and not just memorized, one must develop concepts rather than simply state them. In these chapters, however, facts are simply repeated and little attempt is made to provide the reader with a satisfactory understanding of the underlying principles that determine a given fact.

Following the first six basic-physics chapters, topics are presented at random. Although these topics are important and worthwhile for general information, unfortunately they are confined to the primary interests of the Argonne Laboratory. The topics selected are accelerators, reactors, uranium metallurgy, reactor-fuel processing, radiation effects and radiation biology.

At the end of the book are descriptions of a variety of experiments that pertain to nuclear science. These write-ups are obviously reproduced verbatim from handouts given to course participants. In fact at one point the reader is told that a certain operation will be performed for him by the laboratory staff. The write-ups of the experiments are disorganized and of little use to most readers—including high-school teachers.

As might be expected of a national laboratory, most of the experiments fail to comply with the criterion established in the preface that no expensive equipment will be used. For example five of the experiments require melting, casting and rolling of a uranium-aluminum alloy. Consequently these experiments are completely useless for the high-school teachers because they will be unable to perform them in their own classrooms.

In spite of the fact that this book has little to offer that is not presented better elsewhere, it does have one bonus: at the end of the table of contents the curriculum for the short course is summarized. This is invaluable if a reader wants to teach high-school teachers nuclear science.

Radiation Protection and Recovery

Edited by ALEXANDER HOLLAENDER (Pergamon Press, New York, 1960, $10, v + 392 pages)

Reviewed by DONALD E. KAHLSON, Lockheed Georgia Nuclear Laboratory, Dawsonville, Ga.

The major purpose of this book is to review recent radiobiological investigations. Although the detail of coverage is excellent, the book is definitely too complex for the beginner who needs at least a working knowledge of organic chemistry and biology. The scope of the volume includes living-cell damage and protection and recovery from a chemical-biological point of view. Particular emphasis is given to protective compounds as well as the general chemical phenomenon of radiobiology. In the broad cross section of living tissues considered, specific chapters cover mammals, bacteria, fungi, seeds and roots. Separate treatment of chromosome aberrations, genetic protection, somatic effects, antibody formation and photoreactivation furnish background material in these supplementary fields. The chapter on "Acute Whole-Body Radiation Injury" is among the finest I have ever read in terms of organization and general level of presentation.

The immense volume of literature that has been reviewed in preparing this text is attested by the condensation of 1,548 references into 377 pages. In fact the ratio of references to text is so great that it is often difficult to follow the continuity of thought, particularly because of the lack of consistency in listing references. For example in Chapter 7 the author has the annoying tendency of injecting between thoughts long parenthetical statements giving exacting details for each reference.

In addition, I think that a more uniform treatment throughout the book would have been less trying on the reader. For example 11 curves and graphs are used in the chapter on protection and recovery of bacteria and fungi whereas none are included in the chapter on protection and recovery of seeds and roots. In the latter chapter information that could have been given in curves and graphs is presented in the text, calling for a change-of-pace on the part of the reader. Moreover some chapters end with summaries, some with conclusions, one with general remarks and most without any closing statements whatsoever leaving the reader hanging in the air.

Since this book attempts to take inventory of the status of this growing field, I feel that a glossary would have been helpful, not only for defining terminology but also as a standardizing medium particularly since the subject matter is interesting to people in several different disciplines. Moreover I think that the general value of the text would have been increased if it contained a special concluding chapter that collectively mentioned some of the more important chapter conclusions such as the role of oxygen and *p*H in accommodating radiation damage.

Despite these shortcomings, the over-all level of competence is quite high and the book will no doubt become an authoritative supplement to the "International Series of Monographs on Pure and Applied Biology" of which it is the seventh volume.

BOOKS RECEIVED

Basic Principles of Fission Reactors, by W. R. Harper (Interscience Publishers Inc., New York, 1961, $7.50, viii + 314 pages). For the graduate student with a mathematics and physics background but not necessarily a nuclear engineering one this book outlines reactor theory and the fundamentals of reactor design. Starting with two chapters that give a general background of important nuclear-engineering concepts, the author goes on to discuss power reactors thus setting the scene for the detailed and quantitative discussions of the later chapters. Chapters in the book include material on fissile fuels, fuel elements, neutron sources, moderators, fast, homogeneous-moderated and heterogeneous reactors, control of radioactivity, radiation protection and operating reactors. Although the book is comprehensive and outlines a good introductory course on reactors, when compared to the books by Samuel Glasstone, which are also written for graduate students, it seems to be almost too simplified to give a really thorough understanding of reactors.

Radioactivity in Man, edited by George R. Meneely (Charles C. Thomas, Springfield, Ill., 1961, $16.50, xx + 491 pages). These published papers from the symposium held at the Vanderbilt University School of Medicine in April, 1960, cover all aspects of radioactivity in man from the instruments used to measure or administer it, to its hazards, to administration problems. The book is an excellent survey of the field and should be informative to those persons working in the field and to those interested in getting a general survey of work with radioactivity.

ALSO OF NOTE

Reactor of the World, second series, contains thirteen new reactor foldouts that appeared in *Nuclear Engineering*. These include Pluto, Merlin, G1 (1956), Hinkley Point Power Station, NRU, Halden, Latina, Zenith, G2 and G3, OMRE, Dragon, BR3 and N.S. *Savannah*. Edited by E. N. Shaw. 1961, $3.50 card covers, $4.50 cloth bound, 27 pages. *Simmons-Boardman Publishing Co., 30 Church St., New York, N. Y.*

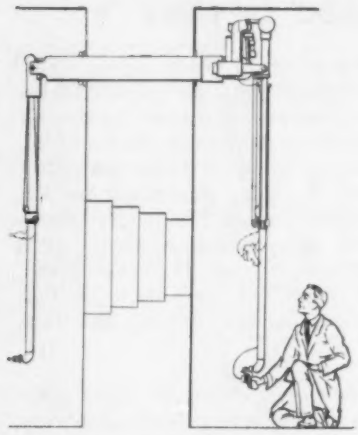
Public Availability of Reports Abstracted in Nuclear Science Abstracts, printed in two volumes, includes an alpha-numeric listing of all reports abstracted in volumes 1–14 of NSA. 1961, $5, 640 pages. *Office of Technical Services, Dept. of Commerce, Washington 25, D. C.*

Tables of Gamma Rays from the Decay of Radionuclides (AECL-1225) includes gamma-emitting radionuclides with half-lives >1 sec listed according to atomic number and suborder of mass number, photon energy, photon energy subgrouped according to half-live and photon energy subgrouped by possible production method. By R. C. Hawkings, W. J. Edwards and E. M. McLeod. 1961, $8, 372 pages. *Scientific Document Distribution Office, Atomic Energy of Canada Ltd., Chalk River, Ontario, Canada.*

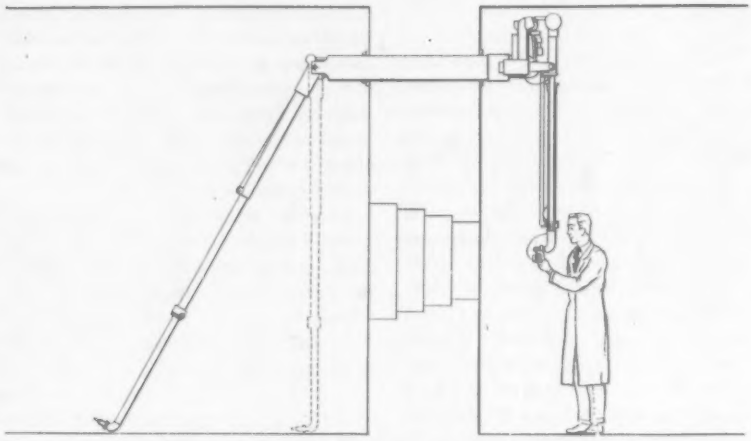
Atomic and Molecular Collision Cross Sections of Interest in Controlled Thermonuclear Research (ORNL-3113). Cross sections are shown as a function of energy for collision processes involving molecular-ion dissociation, charge exchange, excitation, ionization, photo-ionization, scattering, energy loss and recombination. By C. F. Barnett, W. B. Gauster, and J. A. Ray. 1961, $2.75, 161 pages. *Office of Technical Services, Dept. of Commerce, Washington 25, D. C.*

Bibliography on Research on Controlled Thermonuclear Fusion contains about 2,900 references to works published between Jan. 1955 and Dec. 1960. *IAEA, Kaerntnerring 11, Vienna, Austria.*

Extended-Reach Manipulator Triples Volume Covered in Hot Cell



IN PRESENT MANIPULATORS operator must repeat with master end motion of slave end. Thus his positions are often uncomfortable and his reach and view limited



WITH EXTENDED-REACH MANIPULATOR operator stands upright and extends slave end of manipulator with electric switches to double its normal length. Consequently he reaches three times volume in hot cell obtainable at left, he can easily reach objects that are close to cell window or floor and he can see clearly entire operation

With new AMF Atomics master-slave manipulator an operator can reach the floor and corners of a hot cell that are inaccessible with other remote-handling devices. Moreover he can remain in a comfortable erect position while the slave end moves to all areas in the cell (see figures above). Thus the extended-reach manipulator eliminates operation problems of other instruments: limitation in vertical motion of the slave end, problems of cramped quarters while working close to the window, trouble seeing the slave end when working close to the floor.

How are these difficulties overcome? The extended-reach manipulator combines an extra telescope tube in the slave end that can be extended or contracted easily by operating electrical switches at the master end. So that the operator can quickly see whether the manipulator is in the extended or normal position, this extra tube is colored. Thus if he sees no colored tube, he knows the slave end is contracted. When the slave end is extended to its full length—twice normal length—it covers a volume three times that reached by present manipulators; thus it can reach the floor for a circular area with a radius up to 5½ ft. In addition it can reach close to the window—an area in which operation is usually extremely cramped with normal manipulators. Although the reach of the instrument is extended, the tape in the manipulator is no longer than in standard models. Consequently there is no reduction in system "feel."

Extended-reach manipulators come in both standard-duty and heavy-duty models. Moreover since about 60% of the parts are interchangeable with present AMF Atomics models, spare part inventory requirements are small. —AMF Atomics, 261 Madison Ave., New York, N. Y.

Aerial and ground radiation monitor. SBL-2, a portable scintillation detector and recorder (above), is designed for radiation monitoring from low-flying aircraft or at a distance of 3 ft above the ground. Monitor is calibrated for range of 0.2–2,000 mr/hr.—Edgerton, Germeshausen & Grier, Inc., Santa Barbara Laboratory, P. O. Box 98, Goleta, Calif.

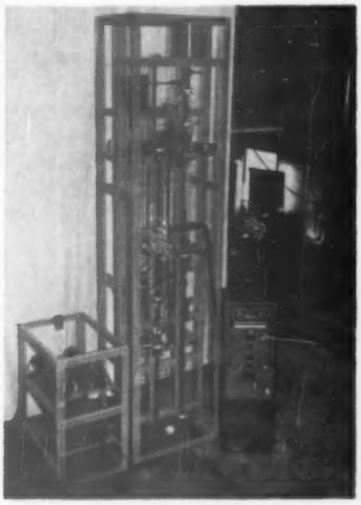
Series of proportional counters, PNI 1077, for low power levels in reactor flux-measuring channels are made of pure aluminum with 94% enriched boron lining. Counter, which has ceramic-to-metal seals and ceramic insulators, operates at low voltages; gas multiplication of 50 occurs at ~750 volts.—Plessey International Ltd., Ilford, Essex, England.

Oxygen analyzer. By recording variations in paramagnetism of a sample gas mixture at a constant temperature, explosion-proof Model 632C measures continually oxygen content in gas with an accuracy of ±2% under normal operation. Measurement is read off a built-in indicator.—Hays Corp., 742 E. 8th St., Michigan City, Ind.

Two electrostatic generators—Model AK600-4 and AKS600-4—rated at 600 kv and 4 ma—provide essentially pure d-c output, low output capacitance, minimal short circuit and overload currents and remote adjustment.

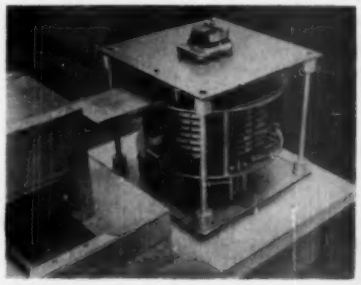
Model AKS 600-4 has ripple of 0.01%, output capacitance of 1,500 mmf; Model Ak600-4 holds ripple to ±1% peak and has output capacitance of 500 mmf.—SAMES, 30 Broad St., New York 4, N. Y.

Automatic gamma analyzer, Model GSS-1B, needs no adjustment to scan, record and analyze emitters with energies from 0.003 kev to 3 Mev. System can analyze gamma spectra from 0.1 kev to 6 Mev. Readout is in three forms: count for preset time period, continuous counting rate and graphic recording. System contains universal shield, linear-count ratemeter and spectrometer, slave scaler and graphic recorder.—Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.



Continuous ion-exchange contactor built for studies of plutonium purifications by anion exchange has been delivered to French Commissariat à l'Energie. Tall assembly in middle (above) is contactor loop, assembly on left contains Lapp Pulsafeeder pumps and cabinet on right contains sequence and conductivity controllers. Except for small size and glass construction, Higgins-type contactor is similar to those used to recover uranium at Oak Ridge and in Japan and plutonium at Hanford.—Chemical Separations Corp., 101 Midway Lane, Oak Ridge, Tenn.

Analog-to-digital converter (Model AD-50A) provides up to five million independent 8-bit words/sec. Machines's 25-nanosec aperture time allows digitizing of pulses less than ½-μsec wide. In typewriter-size converter digital output is parallel straight binary with timing pulse up to eight bits unipolar or up to seven bits plus sign bipolar.—Raytheon Co., 1415 Boston-Providence Turnpike, Norwood, Mass.



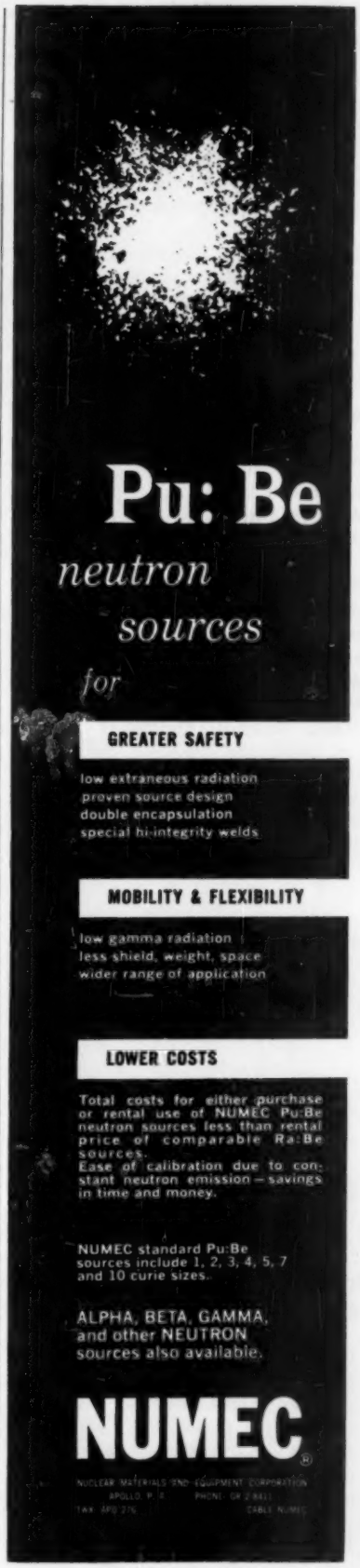
Low-background counting system, the LowBetamatic (above), is a compact three-dimensional sample magazine that counts 84 samples in sizes up to 3 in. in diameter.—Sharp Laboratories, Inc., Box 1302, La Jolla, Calif.

Sampling oscilloscope makes high-resolution measurements of nanosecond pulses. Model 185B gives direct reading and bright-trace observation. When equipped with Model 187B dual-trace amplifier, oscilloscope has pass band from d-c to 1,000 Mc, can be synchronized to 1,000 Mc and has full screen presentation of signals from 0.3 nanosec to 100 μsec.—Hewlett-Packard Co., 1501 Page Mill Rd., Palo Alto, Calif.

Emergency-power source operates from reserve battery sources of 120, 130 or 140 volts d-c to supply up to 750 volt-amp of 115 volts a-c 60 cycle power. Source picks up full load from standstill within 50 msec.—Cornell-Dubilier Electronics Div., 118 E. Jones St., Fuquay Springs, N. C.

¾-in. photomultiplier (Type WX 4582) is ideally suited for oil-well logging because of its size and rugged construction. Photocathode has an S11 spectral response, peaking at 4,400 A. With 105 volts applied in each stage average anode sensitivity is 9 amp/lumen and cathode sensitivity is 50 μa/lumen. Dark current is <0.01 μa.—Westinghouse Electronic Tube Div., Elmira, N. Y.

Equipment cabinets—the Mark V, Series E—contain all electronic equipment and controls not specifically needed in production area. Series includes remote-equipment cabinets and pedestal, wall-mounted and floor-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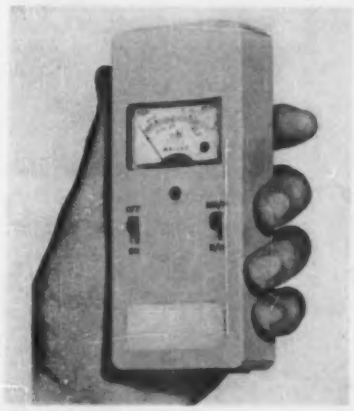
mounted operator's control stations. Cabinets contain separate swing-out panels so components can be easily reached.—Industrial Nucleonics Corp., 650 Ackerman Rd., Columbus 2, O.

Co^{60} in standard capsules (Type 360) or in special capsules to suit customer's specifications has normal focal spot of 1 cm for activities <4,000 curies.—U. S. Nuclear Corp., P. O. Box 208, Burbank, Calif.

Neutron detectors. New proportional counters filled with boron trifluoride (96% B^{10} enrichment) have ceramic-to-metal seals and heliarc welding.—Amperex Electronic Corp., 230 Duffy Ave., Hicksville, N. Y.

Radiation dosimeter reader. Flurometer Models 110 and 111 can be converted quickly into dosimeter readers by using holders containing Bausch & Lomb silver-activated glass dosimeters that fit easily onto Flurometer doors. Range of reader using glass-rod dosimeter is $10–10^5$ roentgens for Co^{60}; using glass plates it is $2–3 \times 10^4$ roentgens; measurement takes <1 min.—G. K. Turner Associates, 2524 Pulgas Ave., Palo Alto, Calif.



Pocket survey meter (above), no bigger than a pack of cigarettes, weighs <8½ oz. Operating on penlight batteries or mercury cells, meter is accurate at temperatures from −20 to +140°F. Three models are available: civil defense model (0.1–2 r/hr and 1–100 r/hr), standard model (0.1–50 r/hr and 0.01–1 r/hr), high-range model (1–500 r/hr and 0.2–50 r/hr).—Gelman Instrument Co., Chelsea, Mich.

Induction billet furnace processes work in vacuum with 10-micron operating pressures. Type N3000 Model 414 consists of bell jar and work coil together with backing pump and high-vacuum rotary blower. Chief advantage is that system rapidly brings billet to forging temperatures with a minimum of oxide formation.—High Vacuum Equipment Corp., 2 Churchill Rd., Hingham, Mass.

Fuel transfer system (above) for Pathfinder plant will convey enriched uranium assemblies from vault in fuel storage facility to the reactor building and spent fuel to storage area. The 50-ft long system, constructed mainly of stainless steel, operates under 18 ft of water. It consists of a metal carriage on wheels that moves on tracks inside two 20-in. diameter tubes aligned on either side of a connecting isolation valve. The loaded carriage travels at five speeds; the fastest is 20 ft/min.—General Mills, 9200 Wayzata Blvd., Minneapolis 26, Minn.

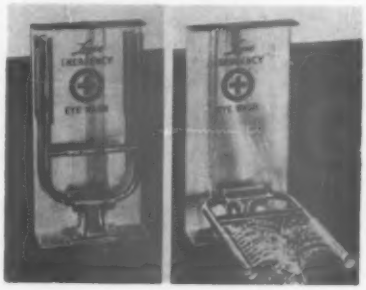
1-Mc decade scaler, a count-to-ten device, uses 8-4-2-1 binary code to count random serial pulses at any rate up to 1 Mc. These units can be cascaded with front panel connectors. Total count is displayed visually on front panels in neon-lighted decimal digits.—Harvey-Wells Electronics, Inc., 14 Huron Dr., Natick, Mass.

Solid-state, medium-sized computer, the Digital Data Processor (DDP), has a 19–25-bit range. Nineteen-bit machine uses 5-μsec, 4,000- or 8,000-word core memory; memory access time is 2.5 μsec. Paper tape feeds in 500–1,000 characters/sec.—Computer Control Co., Inc., 2251 Barry Ave., Los Angeles 64, Calif.

Radiation tests at Brookhaven National Laboratory recently showed that Sylvania gold brand subminiature and guided missile receiving tubes will withstand neutron fluxes of 10^{16} n/cm²/sec.—Sylvania Electric Products Inc., 730 Third Ave., New York 17, N. Y.

Improvement in Packard counters. Two separate channels of pulse-height analysis are now provided in liquid scintillation counters with individually variable electronic amplifications and four adjustable discriminator levels. Moreover changes in electronics allow spectrometer to be used for gamma counting.—Packard Instrument Co., P. O. Box 428, La Grange, Ill.

GE enters diode field with SD-150, a miniature silicon planar, epitaxial, passivated diode to be used in computer circuits. Diode has conductance of 100 ma at 1 volt and recovery time of <2 nanosec.—General Electric, Kelley Building, Liverpool, N. Y.



Decontamination fountain (above) can be used for washing eyes, nose or mouth in case of contamination. When one swings down spray bars water flows across an area 8 in. × 8 in. with very little pressure.—Logan Emergency Showers, Inc., P. O. Box 111, Glendale, Calif.

Radioactive-sample-preparation kit. Using a chimney funnel students can make radioactive samples or planchets with kit. Solution is suctioned filtered through funnel and a uniform layer of sample is deposited and dried on a steel disk.—Nuclear-Chicago Corp., 359 E. Howard Ave., Des Plaines, Ill.

Low-cost scintillator kit, E-160 Scinti-Kit, contains interchangeable phosphors for measuring alpha, beta or gamma radiation. Kit has probe

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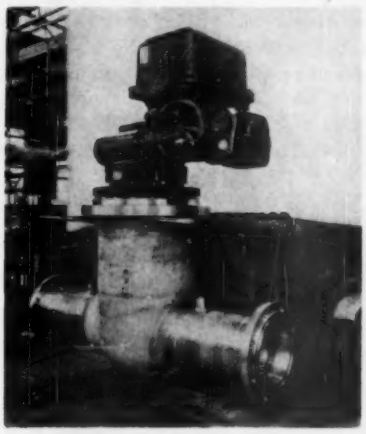
housing, photomultiplier tube and five scintillators: NaI(Tl), NaI(TL), plastic phosphor, zinc-sulfide crystal and anthracene crystal. Cost is $475.—Radiation Equipment & Accessories Corp., Lynbrook, N. Y.



Scram valves for KIWI-B. Four 8-in. motor-operated ball valves (above) for handling liquid hydrogen have 10-sec actuation times. Stainless-steel valves have welded vacuum-tight jackets and operate at low pressures and temperatures (−423–+130°F). Drivers operate at 10,000 psi (0.5-sec activation) or 20,000 psi hydraulic.—Hydromatics, Inc., S. Lawrence St., Bloomfield, N. J.

Recorder (above), available in both 5-in. and 11-in. strip-chart sizes, can operate as standard fixed-span recorder or with one or more external plug-in modules.—Westronics, Inc., 3605 McCart, Fort Worth, Tex.

Memory storage unit, the Microstore high-speed component for analog computers stores two values at a time. As many as 10 of these units—each half the size of a cigarette carton—can be plugged into an EAI PACE 231R analog computer without disturbing summing amplifiers.—Electronic Associates, Inc., Long Branch, N. J.

(*Continued*)

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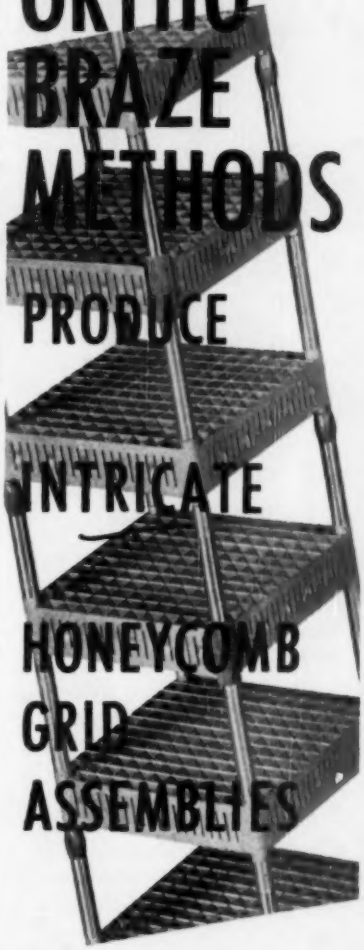

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Products and Materials

Department starts on page 84

Semiconductor detectors. NPSN Series consisting of semiconductor detectors for either fast or slow neutrons are coated with B^{10}, Li^6, U^{235} or a hydrogenous radiator. NPS Series measures electrons, protons, alpha particles, heavy ions and fission fragments. —Solid State Radiations, Inc., 9925 W. Jefferson Blvd., Culver City, Calif.

Plastic shoe covers (above) meet AEC specifications for protection against contamination. Shoes, which have nonslip soles, are waterproof, lint-free, dustproof and washable.—Defense Apparel, 115 Allyn St., Hartford, Conn.

New fast Poloroid film, PolaScope Type 410 Land film, has speed rating of 10,000 (ASA) and increased contrast. Film resolution is ~14–22 lines/mm. This Panchromatic Type B film must develop only 2 sec in camera followed by 8 sec in daylight; entire roll of film can be exposed and processed in <20 sec.—Polaroid Corp., Cambridge 39, Mass.

Magnetic pump for radioactive fluids. Model L-2145 has only one moving part —the pump plunger—activated by a magnetic field. Bore of pump and plunger are covered with stainless steel for corrosion resistance. Pump delivers 4 gallons/min at 30 psi.—G. W. Lisk Co., Inc., Clifton Springs, N. Y.

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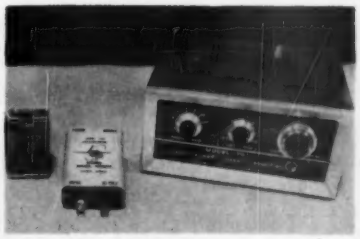

Tiny linear amplifier (above right) for amplifying small pulses from nuclear detectors has a maximum gain of 1,000 times. Model 701 comes with preamplifier that is the size of a pack of cigarettes (above left).—Lockheed-Nuclear Products, 3272 Peachtree Rd., N.E., Atlanta 5, Ga.

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Solid-State Annunciators. 8 pp.; Radiation Technology Inc., 657 Antone St., N. W., Atlanta 18, Ga.

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Current Source (Portable). 2 pp.; Gyra Electronics Corp., Washington & Elm St., Box 184, La Grange, Ill.

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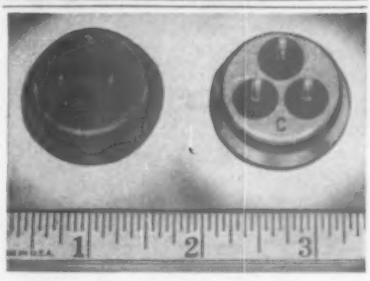

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Nanosecond Instruments and Accessories. 6 pp.; Lumatron Electronics, Inc., 116 County Courthouse Rd., New Hyde Park, N. Y.

By-Products of Fusion Research. 8 pp.; Plasmanetics Corp., Box 398, Berkeley 5, Calif.

Kennertium W-10 Heavy Tungsten Alloy. 8 pp.; Kennametal Inc., Latrobe, Pa.

Atomic Instruments and Systems (Catalog A-5). 50 pp.; Baird-Atomic, Inc., 33 University Rd., Cambridge 38, Mass.

Vehicular Mechanical Arm System. 4 pp.; General Mills, Inc., 419 N. Fifth St., Minneapolis 1, Minn.

Three-Dimensional Closed-Circuit Television. 8 pp.; Stereotronics Corp., 1717 N. Highland St., Los Angeles 28, Calif.

Automatic Closed-Circuit Television. 8 pp.; Kintel, Div. of Cohu Electronics, 5725 Kearny Villa Rd., San Diego 11, Calif.

Bendix G-20 High-Speed Computing System. 6 pp.; Bendix Computer Div., Los Angeles 45, Calif.

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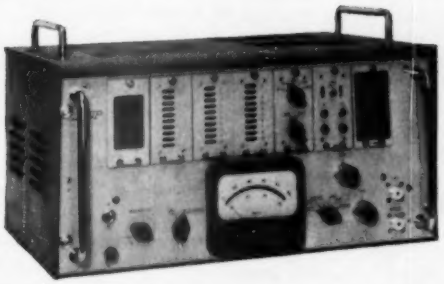

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Products and Materials

Department starts on page 84

Properties of Beryllium. 20 pp.; General Astrometals Corp., 320 Yonkers Ave., Yonkers, N. Y.

Tubular Products. 16 pp.; J. Bishop & Co., Malvern, Pa.

Sylcor Custom Metallurgy Plus Space-Precision Fabrication. 4 pp.; Sylcor, Hicksville, N. Y.

Special Metal Fabrication. 12 pp.; Cook Electric Co., 3412 River Road, Franklin Park, Ill.

Design Manual Valve Remote Control Systems. 20 pp.; Stow Manufacturing Co., Binghamton, N. Y.

Threaded Stainless-Steel Fittings and Valves. 18 pp.; Cherry-Burrell Corp., Cedar Rapids, Ia.

Electric-Cand Pumps. 4 pp.; Allis-Chalmers, Industrial Equipment Div., Milwaukee 1, Wis.

Control Valves. 60 pp.; Fisher Governor Co., Marshalltown, Ia.

New Standards in Rubber Seat Butterfly Valves. 4 pp.; Henry Pratt Co., 319 W. Van Buren St., Chicago 7, Ill.

Radioactivity Demonstrator. 16 pp.; Central Scientific Co.; Cenco Instruments Corp., 1700 Irving Park Rd., Chicago 13, Ill.

Digital Data-Recording and Alarm-Scanning System Brochure. 8 pp.; Monitor Systems, Inc., Industrial Park, Fort Washington, Pa.

Film Reader—Converts Photographic Data to Digital Form. 12 pp.; Itek Laboratories, Lexington 73, Mass.

Thermocouple Assemblies. 42 pp.; Minneapolis-Honeywell Regulator Co., Brown Instruments Div., Philadelphia 44, Pa.

High-Sensitivity Liquid Density Gauges. 6 pp.; Nuclear-Chicago Corp., 333 E. Howard Ave., Des Plaines, Ill.

Transistorized Annunciator Systems. 12 pp.; Rochester Instrument Systems, Inc., 275 N. Union St., Rochester 5, N. Y.

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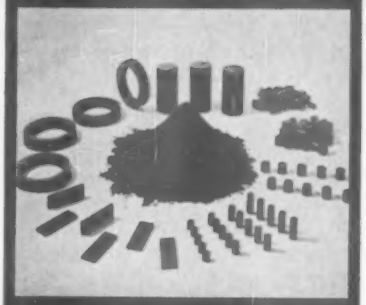

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NEWSMAKERS

Walter F. O'Connell has been elected president and board chairman of United Nuclear Corp. Formerly a United Nuclear board member and chairman of its executive committee, he succeeds **William C. Foster** who has been appointed director of the newly-created U. S. Arms Control and Disarmament Agency.

Union Carbide Corp. has appointed **Clarence E. Larson,** who had been UCC's associate manager for research since 1959, a vice-president of Union Carbide Nuclear Co. and general manager for all operations at AEC's Oak Ridge, Tenn., complex, including the Laboratory and production plants.

George C. Dacey, formerly director of solid state electronics research at Bell Telephone Laboratories in Murray Hill, N. J., has been appointed vice president-research at Sandia Corp., prime AEC contractor for nuclear weapons design and testing.

Wayne D. Stinnett, design engineer formerly managing the Special Projects Division at Aerojet-General Corp.'s liquid rocket plant in Azusa, Cal., has been appointed AGC's NERVA (Nuclear Engine for Rocket Vehicle Application) program technical manager. His responsibility will include integration of the reactor into the engine, engine design and design and development of associated ground support equipment.

Allis-Chalmers Manufacturing Co. has announced three nuclear appointments. **C. R. Braun,** who had been manager of A-C's Nuclear Power Department-Greendale (Wis.), has been named manager of marketing for the Atomic Energy Division. Succeeding him as Nuclear Power Department manager is **C. B. Graham,** who moved up from chief engineer of the department. **M. R. Beebe,** formerly health physicist at Republic Aviation Corp. and Brookhaven National Laboratory, has been appointed supervisor of health physics. He will be responsible for corporate radiation and nuclear safety.

L. C. Widdoes, formerly president of Internuclear Co., a subsidiary of Petrolite Corp., has been named director of research for Petrolite. He will direct research programs for all Petrolite divisions and subsidiaries. He was succeeded at Internuclear by **Carl F. Leyse,** appointed general manager (NU, Oct. '61, 88).

George J. Stathakis, formerly manager of overseas-power reactor applications for General Electric's Atomic Power Equipment Department, has been appointed manager of International General Electric's Atomic Product Sales Section. In other IGE moves, **Robert S. Meltzer** of Atomic Sales has been assigned to the Power Equipment Department's overseas applications component, and **Jack Williams,** also of the Atomic Power Equipment Department, has been assigned to IGE Atomic Sales.

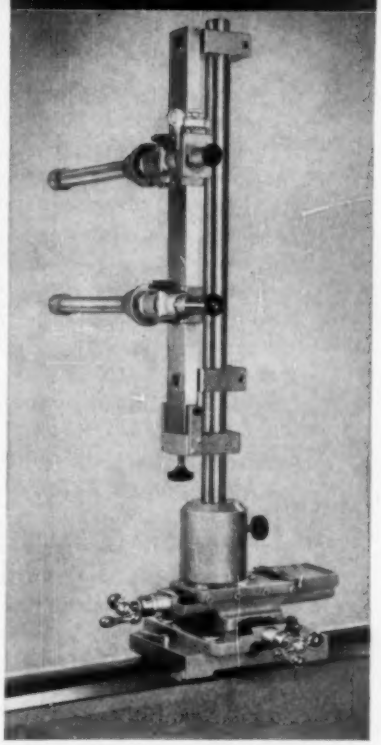
David Saxe has joined Atomics International as manager of administration. The former deputy manager of AEC's Chicago Operations Office will be responsible for contract administration, and for the Financial and Material Departments.

The naming of **F. R. Bruce** of Oak Ridge National Laboratory as assistant deputy director of the lab was one of several recent AEC appointments. Others: **W. H. Pennington,** as assistant manager for technical operations in the Commission's New York Operations Office; **Milton A. Rex,** as assistant manager for field operations in the new Las Vegas Office of Field Operations; and **James E. Reeves,** who had been assistant to the manager of the Albuquerque Operations Office, to head the new Las Vegas Office, which is expected to complete merger with the former Las Vegas area office in about six months.

Morton I. Goldman, nuclear-installations consultant, has joined Nuclear Utilities Services, Inc., Washington, D. C., to work on radioactive waste disposal and reactor environmental safeguards . . . **E. R. Johnson** has been named sales manager, Nuclear Materials, for the Davison Chemical Division of W. R. Grace & Co. . . . **Jerome I. Cohn** has been appointed sales-engineering director of Radiation Materials, Inc. . . . **Robert C. Fraser** has been appointed sales manager of Controls For Radiation, Inc.

Correction: **Boone M. Bowen** was incorrectly referred to in our October issue (pg 90) as Boone Dawson.

INSTRUMENTS TO MEASURE LINEAR DIMENSIONAL CHANGES



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NUCLEAR CALENDAR

International Atomic Energy Agency

Dec. 11–15—Technical Seminar on Agricultural and Public Health Aspects of Radioactive Contamination in Normal and Emergency Situations, The Hague, Netherlands.

Jan. 9–12—5th International Symposium on Radioactive Isotopes in Clinical Medicine and Research, Bad Gastein, Austria.

Dec. 3–7—Annual Meeting, American Institute of Chemical Engineers, Hotel Commodore, New York City, will include full-day session on processing for spent reactor fuels and radiation. Contact: A. V. Caselli, Technical Program Chairman, c/o Shell Chemical Corp., 50 W. 50th St., New York 20, N. Y.

Dec. 4–14—Advanced training course, "Modern Techniques in Activation Analysis," will be followed **Dec. 15–16** by the 1961 International Conference on Modern Trends in Activation Analysis, jointly sponsored by IAEA, AEC and Texas A&M College, at Texas A&M, College Station, Texas. Contact: Richard E. Wainerdi, Head, Activation Analysis Research Laboratory, Texas A&M College, College Station, Texas.

Jan. 8–19—Course on "Medical Aspects of Radiological Health," offered by the U. S. Public Health Service's Division of Radiological Health at its Rockville, Md., laboratory. Contact: Chief, Training Program, Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio, or any PHS Regional Office.

Jan. 15—Final registration date (at normal fee) and date for submission of abstracts for Second International Congress of Radiation Research to be held at Harrogate, Yorkshire, Great Britain, **Aug. 5–11**. Contact: Dr. Alma Howard, Secretary-General, Mount Vernon Hospital, Northwood, Middlesex, England.

Feb. 15–17—Golden Gate Metals Conference, Fairmont Hotel, San Francisco, will be featured by sessions on materials for space and nuclear applications. Contact: Norman McLeod, Office of the Secretary, 1605 Solano Av., Berkeley 7, Calif.

Feb. 24—ANS topical meeting, sponsored by the Pittsburgh Local Section, will consider role of computers in nuclear power plants. Contact: George Weddell, Pittsburgh ANS Chairman, c/o Westinghouse Electric Corp., APD, Box, 1468, Pittsburgh 30, Pa.

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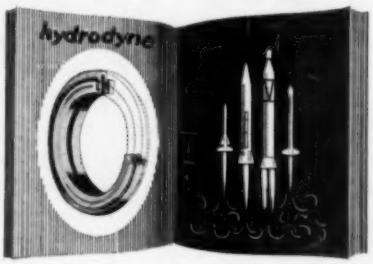

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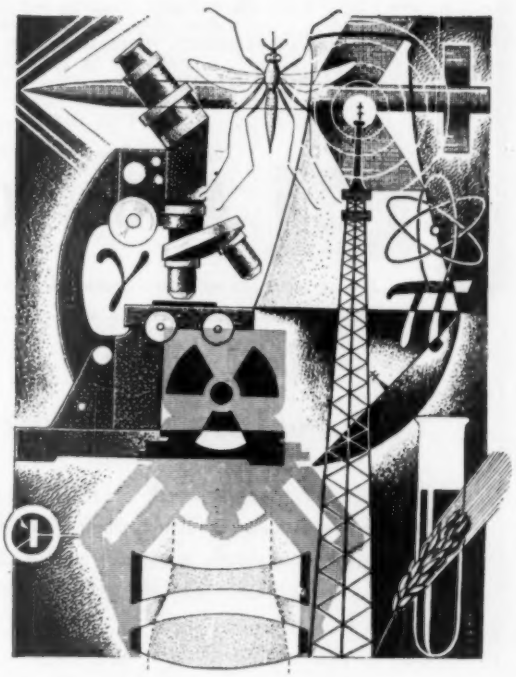

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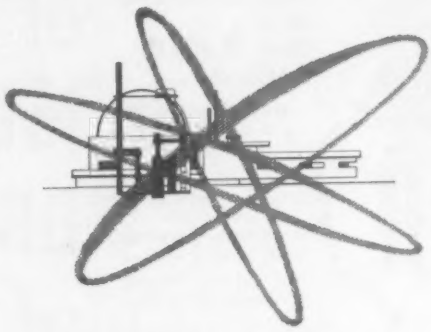

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A Third Space Agency

More than five years ago—when few people were excited about outer space—the Atomic Energy Commission (with the encouragement of the Air Force) quietly inaugurated work on the nuclear rocket, on systems for nuclear auxiliary power and on reactor systems for electrical propulsion. This was a classic demonstration of foresight and leadership on the future for nuclear energy in space.

Five years later, however—when space excitement is general and many are recognizing that nuclear power will be vital to the U. S. space program in many ways—there is an untimely lack of nuclear-space vitality at AEC, except in the Presidentially-blessed nuclear-rocket program. As recently re-emphasized by AEC Chairman Glenn T. Seaborg's statement that "space and the atom . . . were made for each other," AEC's interest in developing space-power systems for satellite, auxiliary and electrical-propulsion uses goes undiminished. But, though its *interest* is at high tide, its *leadership* has ebbed.

Why? We think it's because the demand for nuclear power devices—both reactor and radionuclide types—is moving faster than AEC's rate of development. The U. S. space program has caught fire. But at AEC—in too many ways—it is business as usual on development of the power supplies that could and should be used in many space missions. What has happened? In our opinion, the traditional AEC "requirement for a requirement" has been antiquated by the accelerating development of large rocket boosters, satellites of various types, and electrical-propulsion engines. It is obvious to many at AEC and in the nuclear industry that anyone who wants to run a communications satellite for five years or more will need radionuclide or reactor power supplies (Seaborg, in his Oct. 24 speech at Las Vegas: "There are now more than 20 defined national space missions which could use [the type of radioisotope generator used in Transit IV-A]"). The same is true, in an even more crucial sense, for electrical propulsion (again Chairman Seaborg: "For deep space missions . . . electrical propulsion seems necessary, and it apparently can be achieved only with nuclear-reactor power sources.").

It is clear that the importance of nuclear power to this country's space activities is rapidly pushing AEC into the role of a third, *un*official space agency. But, unlike the two *official* space agencies—NASA and the Defense Department—there is little power at AEC to initiate, because of its dependency on formal development requirements from these agencies and because the Administration has failed to recognize that the investment in nuclear power supplies has not kept pace with their speedily unfolding importance. Thus, the pace of space-nuclear-power development is set—not by AEC—but by agencies whose nuclear capability and interest are limited and where prejudices against things nuclear still run high.

As a result, many space missions over the next several years will suffer because of inadequate power supplies.

We urge that the following steps be taken, as quickly as possible, by AEC and the Kennedy Administration:

1. By AEC, a step it can take internally to underscore the importance it attaches to its nuclear-space responsibilities: the upgrading in rank of the managers of its space projects. Nothing less than men of top managerial calibre and fighting qualities should be acceptable and they should be given appropriate stature.

2. Again by AEC, the abandonment of the obsolete insistence on a development requirement from NASA and/or the AF; and a decision to embark on an aggressive program of space-power-supply development.

3. By the Administration, formal recognition of AEC as a third space agency and a mandate to AEC to meet the space-power needs it *knows* will arise as the accelerating space program matures.

Despite the opportunity presented by a rare display of initiative 'way back in the Lewis L. Strauss tenure at AEC, this country again faces the prospect of having too little—too late—in space.

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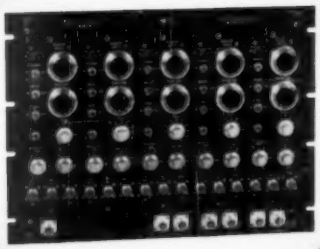

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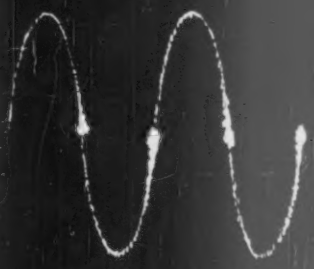
SEE 

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